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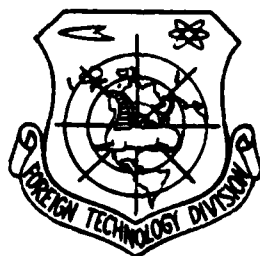
# FOREIGN TECHNOLOGY DIVISION



FUNDAMENTALS OF AERONAUTICAL AND AEROSPACE MEDICAL SCIENCE

by

Cai Qiao, Feng Genquan, and Yan Yuanfu



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### SYNOPSIS

This book presents a developmental history of aeronautical and aerospace medical science, analyzes of aeronautical and space navigation environmental conditions, especially the aeronautical and space navigation environmental conditions related to medical science, and explores the general laws of man's relation to aeronautical and space navigation environmental effects. This book also introduces medical science problems related to gravitational changes and powered flight, analyzes the influence of weightlessness on the human body and offers relevant medical measures. Furthermore, it also introduces the effects of oxygen deficiency, radiation and environmental temperature on the human body and relevant medical guarantees.

This book can act as a reference for aeronautical doctors, aerospace medical personnel, flight physical health inspection doctors, flight personnel, astronauts and those engineers and technicians engaged in aircraft and airship design.

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## PREFACE

Although aeronautics and space navigation have differences in altitude, speed, time and range of manoeuvres, their environmental factors influencing the human body are generally the same. Moreover, aerospace medical science developed on the foundation of aeronautical medical science and because of this, it is quite suitable to place the two together for discussion.

This book uses the following three aspects to introduce the basic knowledge of aeronautical and aerospace medical science:

1. We do not follow the traditional style of writing about aeronautical medical science but rather we summarized the environmental factors in aircraft cabins and aerospace areas touched upon in modern aeronautical technology. We chose an expository style of concrete analysis for concrete things and divided the chapters to discuss the influences of these factors on the human body and protective methods against them. The various environmental factors acting on the human body in flight produce the objective material basis of aeronautical and aerospace medical science and without these environmental factors acting on the human body there can be no modern aeronautical and aerospace medical science. Therefore, it can be said that aeronautical and aerospace medical science is a particular type of environmental medical science.

2. Following the deeper recognition by mankind of this

particular branch of environmental science, its application has been expanded and its division within the scientific world has become more detailed. Not only is common aeronautical medical science taken as a major problem in military aeronautical medical science but it has also taken on special features in civilian aeronautical medical science, aerospace medical science and aeronautical human body engineering. This has caused modern aeronautical and aerospace medical science to split off and tend to become an applied science and basic knowledge. This book mainly elaborates on the fundamental knowledge of aeronautical and aerospace medical science.

3. The depth and breadth of environmental medical science knowledge needed by aeronautical doctors, flight physical examination doctors, aircraft and airship design personnel, aerospace medical personnel, flight personnel, astronauts and navigators in their work is different. To satisfy their common needs, this book introduces things of a general nature whereby the various common environmental factors in flight, their effects on the human body and their physiopathological characteristics and mechanisms are taken as starting points for the various disciplines studying aeronautical and aerospace medical science.

In addition, sometimes environmental health problems also occur in national defense construction, industrial production, communications and transportation and physical motion similar to those in aeronautics and space navigation.

For example, there are the well known severe cold and lack

of oxygen in high mountains and plateaus and the noise, vibrations, high temperatures, radiation, atmospheric pollution, motion sickness and decompression sickness in national defense construction, industrial production and communications and transportation. The phenomena and theoretical knowledge narrated in this book also have reference value for health care personnel and engineers and technicians working in these fields.

The above was boldly attempted when the authors were writing this book. Because the levels of the authors are limited, it was difficult to avoid mistakes. It is hoped that readers will offer criticism and point out the mistakes.

In the process of writing this book we received great support from leading comrades of the General Logistics Department and Health Office of the Chinese Civil Aviation Bureau and the entire manuscript was checked over by comrade Meng Fanrong of the Fourth People's Hospital in Peking. Here we would like to express our thanks to those comrades who helped in the work for this book.

## PART ONE

### GENERAL DISCUSSION

#### General Remarks

The overall purpose of socialist medical science is ensuring the people's health and this is also the general task of China's aeronautical and aerospace medical science. For medical science to ensure the people's health, it is necessary to start in several areas. Generally speaking, they are paying attention to hygiene, preventing illness, curing illness, strengthening the physique and in special work it is necessary to guarantee life safety and maintain work efficiency (labor protection).

Aeronautical and aerospace medical science is a synthesis which developed in the practice of aeronautics and space navigation, is a branch of many types of medicine and is a particular environmental medical science. Environment can be divided into natural environment and aircraft cabin environment. Natural environment points to the physical condition and factors in the sky and outer space and cabin environment indicates the environment that flight personnel come in direct contact with. The environmental conditions and factors that can cause the human body to produce effects, whether they are from the natural world, from aircraft motion or from the human body itself are all problems that are discussed in this book.

The reason why environmental conditions and factors are



important is because they can cause a series of physiological effects. Among them, the strong ones which last quite long or change very quickly cause physiological effects that are excessively severe and which people cannot endure. This influences flight operation, can cause the development of a pathological process or functional and organ injury.

When compared with ground conditions, aeronautical and space navigation conditions are more particular and the properties of each factor are different toward human body actions. Moreover, the body is influenced by the independent action of a single factor or the combined actions of many factors, the length of action time and the changes of stimulant strength. Therefore, physiological effects and pathological changes are varied. For convenience of discussion, we must break down the whole aeronautical and space navigation environment into certain factors. Some of these factors arise from the atmospheric environment and outer space; for example, upper atmospheric low pressure, low temperature, ozone, radiation etc. Some occur in the movement of the aircraft and the waste material from navigation personnel; for example, the overload produced by acceleration and airflow shock, high speed turns, deceleration and impact in the ejection life saving process, the vibrations and jolts produced when an aircraft is changing position, the vibrating noise and heat produced by the power equipment, and the high temperature, carbon dioxide and stink produced when cabin ventilation is unsatisfactory. These environmental factors influence the human

body and make up the major contents of this book.

The human body's reaction to aeronautical and astronautical special environmental factors is also very complex. The human body is an organic whole and unless the central nervous system and the body fluid transmission system are injured, the activities of each organ and each system in the human body should be coordinated. However, the reactions of certain factors in specific conditions and in fixed times are emphasized as their local reactions are very noticeable. For convenience of narration, we distinguished the physiological effects to narrate the reactions of each organ and each system. This book uses a great deal of space to discuss the human body's endurance, protection, adaptation and acclimation to aeronautical and space navigational environmental conditions. The aim of providing all of the parameters of medical assurances, medical supervision and aircraft design is to provide a basis of engineering and medical measures for seeking safety guarantees.

## CHAPTER ONE

### THE DEVELOPMENTAL HISTORY OF AERONAUTICAL AND AEROSPACE MEDICAL SCIENCE

Very early man possessed the ideal of going into space. Chinese ancient myths also have these types of fantasies such as the stories of "Chang E fleeing to the moon" and "great havoc in heaven". On the other hand, the working people of ancient China designed and constructed various types of flying machines to soar into space such as kites, Kong Ming's light, bamboo dragonflies, wooden birds and rockets. Yet, because China was under feudalism for so long and was invaded and enslaved by imperialism during the last over one hundred years, there was no aeronautical and aerospace medical science to speak of.

After liberation, under the care of the party and government, China's aeronautics industry developed quickly and there were many successful launchings of earth satellites which showed that Chinese aerospace technology had entered a new stage. In the field of aeronautical and aerospace medical science, China not only has independent training schools and research organizations but also has a scientific research contingency and large group of aeronautical doctors thus forming China's aeronautical medical science contingency.

In the West, the development of ancient aviation was about several hundred to one thousand years behind that of China. For

example, the predecessor of the balloon, the smoke bag, which is like China's small spherical light (the Kong Ming light) was invented one thousand years later than the ones in China. Rockets were first invented in China during the Tang dynasty and by the Yuan and Ming periods they were used as weapons to resist aggression. Only at the beginning of the nineteenth century did foreign reference begin to mention "Chinese rockets" and they were only quoted as strange tales.

The development of capitalist production in the West during the eighteenth century provided an opportunity for scientific and technological development. The predecessor of the balloon, the smoke bag, was invented and gave rise to attempts for balloon launchings. In 1783, the first balloon was successfully sent up to an altitude of 450 meters. During the 100 years up to 1875, many balloons were sent up and some carried people up to an altitude of over 8,000 meters. During that time, many accidents occurred; some suffered frostbite because of the cold and others lost consciousness because of lack of oxygen. Finally, in 1875, three Frenchmen used a balloon with a suspended basket to ascend to over 8,000 meters. Because of lack of oxygen two died and when the remaining man fell to earth he seemed to have lost consciousness. After this, the fervor of balloon aviation gradually declined. During this period, there were people who made atmospheric pressure cabins for people to use and carried out a great deal of experimental research related to low pressure, pressurization and low pressure. This stage can be said to be the embryonic period of

aviation medicine.

Modern aircraft design and manufacture began at the end of the nineteenth century, but actual flight tests began in the beginning of this century and aircraft were first generally used during the First World War (1914-1917). At that time, the highest aircraft flight was only one to two thousand meters and speed did not exceed 500 kilometers per hour. Although this being the case, there still were medical problems that awaited resolution. For example, airsickness, landing accidents, aircraft collisions, injuries from enemy gunfire, forced landings and the problems of first aid, checkups, selection and training closely related to these accidents. The practical needs of warfare brought about the emergence of aviation medicine. The armed forces required aviation doctors and aviation doctors needed to research and solve aviation medical problems. In the latter part of a war or the period after a war, each participating nation, especially the defeated, sets up a special aviation medicine organization responsible for training and research.

During the period after World War One, there was stagnation in aviation development and thus the progress of aviation medicine was also relatively slow. When World War Two was brewing activity was again restored. During the war, because of aircraft flight altitudes and the extension of flight time, unprecedented problems emerged, such as frostbite, hypoxia, decompression sickness, flight fatigue, sight obstruction and overload which urgently needed timely research and solution. During this period, many nations vied to set up special organizations and carried out aviation medical research and

training. There were many achievements in the field of aviation medicine. The jet type airplane appeared near the close of World War Two. After the war, supersonic jets advanced at a tremendous pace. Flight altitude, speed and range notably increased and at the same time there was even faster development in aviation medicine.

After World War Two, the fast development of rocket technology promoted the development of space navigation. From the 1949 biorocket (a rocket carrying a living being into space) to animals in circum-earth orbit, in less than ten years, man eliminated the obstruction of going to outer space. Aerospace medicine developed quickly on the basis of general medicine and aviation medicine. Now, mankind can not only orbit the earth for long periods of time, but, for example, man can stay in a space laboratory for several months and has already landed, traveled and made investigations on the moon. Navigators, whether in space stations, on the surface of the moon or in flight have shown no impairment to their health or had any serious influence on their work. These phenomena cannot but be attributed to the achievements of aeronautical and aerospace medical science. Looking forward to the future of interplanetary flight the development of aeronautical and aerospace medical science has a very broad future.

The development of space navigational technology also promoted the development of aeronautical technology. At present, supersonic aircraft can fly in isothermal layers and the health and safety of people in these aircraft can also be guaranteed.

It can be said that aircraft flight environment is progressively approaching that of spaceships thus causing closer relationships of aviation medicine and aerospace medicine. Actually, they have already been merged and it is hard to draw a sharp line between the two.

## CHAPTER TWO

### ENVIRONMENTAL CONDITIONS OF AVIATION AND SPACE NAVIGATION

#### Section One - Space Environment, Inner Cabin Environment and Environment in the Human Body

There are many differences in the environmental conditions encountered in aviation and space navigation and the environmental conditions of life on the earth's surface. The environmental conditions of aviation and space navigation can generally be divided into three types. The first type is the aircraft environment which is the environment of the outside of the aircraft and spaceship cabin. The second type is the environment inside the cabin which is the small environment which is the environment inside the aircraft and spaceship cabin which some people call the "microclimatic environment". In high altitude flight and space navigation, because the environment is not suitable to human existence, it is necessary that the aircraft and spaceship use an airtight cabin to guarantee that the environment inside the cabin is suitable to the needs of the human body. In low altitude flight, aircraft generally do not require the use of an airtight cabin because when in low altitude flight the environment inside and outside of the cabin is basically the same. The above mentioned two types can be generally designated as "the environment outside the human body". The third type is the body cell environment which is called the "internal environment" of the human body. Because of the human body's own regulations, the internal environment is basically stable and is



maintained in a dynamic equilibrium. When changes occur in the outside environment or because of illness human biological activity cannot proceed normally, imbalance and instability can occur in people's internal environment. If these types of imbalanced and unstable phenomena surpass the body's own regulation capacity and level of endurance and they cannot be reversed and restored quickly, this can cause pathological changes, injury and even death.

As regards the specific conditions of aviation and space navigation, outside environmental changes, especially aircraft environment changes, are often the major aspect of a contradiction. The higher the flight, the faster the speed, and the greater the difference between the environment and the earth's surface the more intense the influence on the human body. To guarantee bodily safety, it is necessary to use an airtight cabin to create an environment inside the cabin suitable to the needs of the human body. Yet, the surrounding environment has an enormous influence on the environment inside the cabin. When the internal cabin environment safeguard system breaks down, these influences become even greater. These changes in the outside environment acting on the human body, in view of the body's physiological mechanisms and internal regulations, cause the internal environment to produce various reactions and changes. Therefore, before discussing the specific contents of aeronautical and aerospace medical science, we need to first introduce the environmental conditions of aviation and space navigation which are the environments inside and outside of the cabin.

Furthermore, the atmospheric conditions in the environment outside the cabin are very important.

## Section Two - Atmospheric Conditions

In aviation and space navigation, the space range not only includes the earth's atmosphere but also includes cosmic space outside the atmosphere. Yet, when discussing atmospheric conditions, it is essential to speak of the earth's atmosphere.

The atmosphere encircling the earth follows the rotation of the earth and revolves. From the earth's surface upwards, it gradually changes from dense to thin and therefore the higher the altitude the lower the atmospheric density and pressure. At an altitude of 50-100 kilometers, airlift is basically lost. The atmospheric air power resistance limit is approximately above 3,200 kilometers. Based on statistics, the centrifugal force and centripetal force positions of the revolving atmosphere are at an altitude of several ten thousand kilometers over the equator which is the ideal altitude of the earth's atmospheric layer. This is called the outside realm of the atmospheric layer. Even though the spatial distribution of the atmosphere is very extensive yet 99% of the atmosphere lies at an altitude less than 32 kilometers. Meteorological phenomena are directly related to atmospheric movements. Therefore, complex meteorological problems are mainly in the less than 32 kilometer range. The relation of meteorological phenomena and aviation is especially great and after spaceships leave the earth, meteorological influences do not exist. Yet, during takeoff and

return to earth there is no way of eliminating the influences of meteorological phenomena. The reader is referred to table 1-1 for the separate layers of the atmosphere.

Table 1-1. Separate layers of the atmosphere.

① 大气层	② 亚层	③ 高度 (公里)	④ 温度 (°C)		⑦ 极端值
			⑤ 下界处	⑥ 上界处	
⑧ 基 层	⑬ 基底层	0~0.002	—	—	-50~+80
	⑭ 高层	0.002~2	—	—	-40~+40
⑨ 对 流 层 (对流层)	⑮ 平 移 层	2~8	+10	-40	+20~-45
	⑯ 对流顶层	8~12	-40	-55	-35~-80
	⑰ 等温层(平流层)	12~34	-55	-50	-45~-65
⑩ 同 温 层	⑱ 逆温层	⑳ 中间层 34~48	-50	+50	-60~+80
	㉑ 混合层		+50	-80~-113	-113~+70
	㉒ E层	85~153	-70	+50	-80~+100
⑪ 电离层(磁层)	㉓ F层	153~400	?	?	+80~+100
	㉔ 原子层	400~800	?	?	+1200(?)
⑫ 大气外层 (散逸层、散射线)	㉕ 大气外层	>800	?	?	+2000(?)

1. Atmospheric layer
2. Sublayer
3. Altitude
4. Temperature (°C)
5. Lower position
6. Upper position
7. Extreme value
8. Base layer
9. Troposphere
10. Stratosphere

11. Ionosphere (warm layer)
12. Outer layer of the atmosphere (dissipation layer, scatter layer.
13. Base bottom layer
14. Upper layer
15. Translatory layer
16. Top layer of atmosphere
17. Isothermic layer (stratosphere)
18. Inversion layer
19. Mixed layer
20. Middle layer
21. E layer
22. F layer
23. Atomic layer
24. Outer layer of atmosphere

#### 1. Aviation Atmospheric Conditions

Aviation is carried out in the atmosphere at an elevation below 50-100 kilometers. Based on modern meteorological data, the atmospheric layer includes the base layer, troposphere and stratosphere.

The atmosphere's base layer is the lowest layer which encircles the earth and its altitude is below 2 kilometers. The layer can be further divided into two sublayers: the lowest layer is called the base bottom layer and is only two meters from the earth; the higher layer is called the upper layer and is 2-2,000 meters from the earth. Because the base layer is greatly effected by topographic height, solar radiation intensity and the seasons, the changes of airflow and wind and clouds are more frequent and complex. Moreover, there is also the takeoff and landing space and therefore ground and air personnel must pay particular attention to the meteorological layer.

The troposphere, also called the changing temperature layer, is above the base layer. This layer derived its name from the fact that its upper and lower air usually produce convection. This layer occupies approximately 79% of the total atmosphere and holds almost all of the vapor and microdust in the atmosphere. Its altitude follows the different earth latitudes and thus is diverse. For example, 16-18 kilometers above the equator, the mid-latitude area is 10-12 kilometers and the two extreme areas are 7-10 kilometers. In this layer, temperature gradually drops in accordance with the higher altitude. The temperature drops an average  $0.65^{\circ}\text{C}$  per 100 meter ascent. Within this layer, there are usually the meteorological changes of wind, clouds, rain, fog, ice and hail and this layer is a main activity area in modern aviation.

Above the troposphere is the stratosphere. Its lower altitude is 12 kilometers and its upper altitude extends to 85 kilometers. This layer can be divided into three sublayers: the isothermic layer, inversion layer and mixed layer. The latter two are jointly called the middle layer. The isothermal layer is also called the stratosphere. Its lower section lies on the upper part of the stratosphere and its upper section extends to about 34 kilometers. The airflow in this layer is relatively stable. Under 25 kilometers, the temperature is generally maintained at about  $-55^{\circ}\text{C}$  and above 25 kilometers, the temperature increases in accordance with the rise in altitude. The air in this layer occupies about 20% of the total atmosphere. The amount of vapor and microdust in this layer

is small, atmospheric pressure is very low and furthermore there is an ozone component.

The middle layer is the transitional moving layer of the isothermal layer toward the ionosphere. Its inversion layer extends from the apex of the isothermal layer to an elevation close to 48 kilometers and this layer seems to have no vertical movement of air. Yet, atmospheric temperature rises in accordance with altitude increases and the highest temperatures can reach to  $-3$  to  $+50^{\circ}\text{C}$ . The space range of the mixed layer is at an altitude of 48-85 kilometers and it has corresponding strong upper and lower airflow movement. Its atmospheric pressure drops radically in accordance with altitude increases and the temperature at the highest point can decrease to  $-83^{\circ}$  to  $-113^{\circ}\text{C}$ .

## 2. Atmospheric Conditions of Space Navigation

The space range of space navigation includes the atmosphere's ionosphere and dissipation layer and the vast cosmic space outside the earth's atmosphere. Generally speaking, the atmosphere in this space range is very thin, the cosmic space outside the atmosphere is close to being a vacuum and the actions of meteorological factors are very small. However, meteorological factors have a certain amount of action in the ionospheric and dissipation layers relatively near to the earth's surface.

The ionosphere is also called the warm layer and its distribution in the 85-800 kilometer altitude range can be divided into the

E layer, F layer and atomic layer. Atmospheric temperature in the ionosphere quickly increases in accordance with increases in altitude. The temperature at its highest point is 500-1,200°C but its air capacity only occupies 0.5% of the earth's total atmosphere. Because the air is very thin, therefore atmospheric temperature has very little influence on flight and the air's transmission of sound has also basically disappeared. The atmosphere of this layer is not only very thin but is also in an ionization state. Because of this, radio waves can attain long distance transmissions around the earth. The ionosphere is greatly influenced by solar activity and it is an essential space layer for satellites orbiting the earth.

The dissipation layer is the outermost layer of the atmosphere and is also called the scatter layer. The altitude of this layer is above 800 kilometers and reaches up to several ten thousand kilometers. This layer's air is extremely thin and continually dissipates toward interplanetary space. Since the air is already thin there is basically no effect on flight. The physical conditions of this layer's atmosphere are more or less the same as interplanetary space conditions. Cosmic space outside the atmosphere is close to a vacuum and its gas composition is shown in table 1-2. To provide the reader with a general idea of the end altitude of various physical characteristics on the earth's surface, table 1-3 is given for reference.

Table 1-2. Interplanetary Gas Composition

① 粒 子	② 每立方米气体中的粒子数	③ 粒 子	④ 每立方米气体中的粒子数
⑤ 电子	$11 \times 10^6$	⑩ 钾	10
⑥ 氢	$1 \times 10^6 \sim 2 \times 10^6$	⑪ 钙	0.12~4.8
⑦ 氦	$10^6$	⑫ 钛	0.05
⑧ 氧	$10^6$	⑬ 碳水化合物	0.4~3.4
⑨ 钠	0.8~107	⑭ 氨基	0.3~1.8

1. Particle
2. Number of particles per square meter of gas
3. Particle
4. Number of particles per square meter of gas
5. Elections
6. Hydrogen
7. Helium
8. Oxygen
9. Sodium
10. Potassium
11. Calcium
12. Titanium
13. Carbohydrate
14. Cyanogen

Table 1-3. End Altitude of Various Physical Conditions on the Earth's Surface.

① 物 理 条 件	② 终止高度(公里)	③ 备 注
④ 大气温度	11~12	⑤ 指进入同温层, 温度低达-56℃
⑥ 氧分压(缺氧)	15~18	⑦ 2公里以上即可出现缺氧轻度症状, 5公里以上症状明显, 8公里以上不供氧即有失意识危险, 7~9公里以上不供氧会引起死亡
⑧ 气压(体液沸腾)	19~20	⑨ 7公里以上减压症状开始出现, 8~10公里以上即可出现体内气泡和气栓塞, 18公里以上必须使用全身加压服才能保持生命安全
⑩ 密闭舱	22.5(22~24)	⑪ 40~80公里以上高度, 密闭舱不能利用压缩周围空气来供应舱内气体
⑫ 原始宇宙辐射	30~40	⑬ 除地球辐射带外, 宇宙辐射强度与宇宙空间中相似
⑭ 太阳电磁辐射	40~50	⑮ 在此高度以上, 太阳电磁辐射强度达到与宇宙空间中相似
⑯ 宇宙黑暗	100~160	⑰ 在此高度以上, 大气和尘埃的光散射作用基本消失
⑱ 流星	125(70~140)	⑲ 一般流星在70~140公里高度上焚毁, 只有少数较大的流星才能到达70公里以下高度
⑳ 宇宙寂静	100~150	㉑ 在此高度以上, 空气的传声作用丧失
㉒ 空气热力学作用终点	160~300	㉓ 在此高度以上, 无由大气而来的热作用
㉔ 空气动力学作用终点	160~200	㉕ 此卫星不受空气阻力及摩擦而毁灭的高度为1千公里, 一般空气升力终点为50公里
㉖ 内辐射带	②⑦ 上界1万	㉗ 南纬35°~北纬35°地区上空, 下界为350~1500公里
㉘ 外辐射带	②⑧ 上界5~6.4万	㉙ 南纬35°~北纬35°地区上空, 下界为1~8万公里
㉚ 大气层	②⑨ 1~10万	㉛ 一般在2~3千公里以下
㉜ 地球的内引力场	②⑩ 上界100~150万	
㉞ 地球与月球引力场平衡点	②⑪ 34万	

Table 1-3 (Key-next page)



1. Physical condition
2. End altitude (kilometers)
3. Remarks
4. Atmospheric temperature
5. When entering isothermal layer, temperature as low as -56°C
6. Oxygen pressure (lack of oxygen)
7. Above 2 kilometers light symptoms of lack of oxygen can appear; over 3 kilometers symptoms are apparent; over 6 kilometers there is no oxygen supply and the danger of loss of consciousness; over 7-9 kilometers there is no oxygen supply and this can cause death.
8. Atmospheric pressure (body fluid boiling)
9. Over 7 kilometers decompression symptoms begin to appear; over 8-10 kilometers internal air bubbles and gas embolisms can appear; over 18 kilometers it is necessary to use a pressure suit to maintain life safety.
10. Airtight cabin
11. At altitudes over 40-80 kilometers, airtight cabins cannot use compressed surrounding air to supply gas in the cabin.
12. Primary cosmic radiation
13. Aside from terrestrial radiation areas, cosmic radiation strength is similar to that in outer space
14. Solar electro-magnetic radiation
15. Above this altitude solar electro-magnetic strength reaches the same as that in cosmic space
16. Cosmic darkness
17. Above this altitude, atmospheric and dust light scattering basically disappear
18. Meteors
19. Generally, meteors burn up above altitudes of 70-140 kilometers and only a minority of larger meteors can reach below an altitude of 70 kilometers
20. Cosmic stillness
21. Above the end altitude, air transmission of sound is lost
22. Terminal point of air thermodynamic action
23. Above the created altitude, there is no means of atmospheric heat action
24. Terminal point of air dynamics
25. Here satellites are not effected by air resistance and friction and the altitude of destruction is 1,000 kilometers. Generally the air lift terminal point is 50 kilometers
26. Internal radiation zone
27. Upper bound 10,000
28. From above an area of southern latitude 35° to northern latitude 35°, lower bound is 350-1,500 kilometers

29. External radiation zone
30. Upper bound 50,000-64,000
31. From above an area of southern latitude 35° to northern latitude 35°, lower bound is 10,000-30,000 kilometers
32. Atmospheric layer
33. 10,000-100,000
34. Generally, under 2,000-3,000 kilometers
35. Earth's internal gravitational field
36. Upper bound 1 million to 1 million 500 thousand
37. Equilibrium point of earth and moon gravitational field
38. 340,000

### Section Three - Medically Related Aviation and Space Navigation Environmental Conditions

The special environmental conditions in aviation and space navigation related to medicine can be generally divided into five major categories: (1) environmental conditions related to gravitational changes and dynamic flight; (2) gas environmental conditions; (3) temperature environmental conditions; (4) radiation environmental conditions; (5) sanitation conditions in spaceship cabin.

#### 1. Conditions Related to Gravitational Changes and Dynamic Flight

Under dynamic flight conditions, aircraft and spaceships produce a series of physical conditions which cause many physiological reactions in the human body and some even cause injury. The following several types are the major ones among these conditions:

1) Acceleration and deceleration: overweightness is the principal reaction produced on the human body.

2) Impact: this is when aircraft and spaceships have impact with the earth or other substances. Although the time is very short (<0.3 seconds), it is still a type of deceleration with a very high

overweight growth rate.

3) Airflow shock: the very high speed airflow shock encountered the instant a human body is ejected from an aircraft.

4) Vibration: there is a definite influence by aircraft and spaceship vibration on the human body.

5) Shaking: aircraft shaking can be encountered in low altitude, high speed flight.

6) Rotation, vibration and turning somersaults: when an aircraft does stunt flying and ejection, unfavorable airship control system functioning and other conditions arise.

7) Noise: aircraft and spaceship noise are produced by the power equipment and has a certain influence on hearing and work efficiency.

Besides the above mentioned conditions related to dynamic flight, when an aircraft is in parabolic flight, when a spaceship orbiting the earth and when a spaceship carries out non-powered free flight in outer space, the disappearance of gravity is called weightlessness. When a spaceship lands on another celestial body, because the other celestial body's gravitational conditions are different from earth's, for example, the moon's gravitational force is only one-sixth that of earth's and people are subject to long periods of low gravity. Therefore, the control of the influence of weightlessness and low gravity is one subject within aerospace medicine.

## 2. Aviation and Space Navigation Gas Environment

There is a great difference between the aviation and space

navigation gas environment and that of earth. It is composed of atmospheric pressure and density and follows altitude changes. Below we introduce the main related environmental conditions.

1) Low pressure lack of oxygen: because at high altitudes air pressure is very low there is a lack of oxygen which causes anoxia.

2) Decompression: at high altitudes atmospheric pressure is very low and when an aircraft ascends very quickly this can produce rapid decompression and bring about decompression sickness.

3) Explosive decompression: because of fighting, meteor collision or other accidents causing air leaks in the airtight cabin, pressure within the cabin suddenly drops. This type of explosive decompression causes the gas in a person's sinuses to quickly expand thus bringing about various types of injuries.

4) Oxygen poisoning: if the air supply system in aviation and space navigation is imperfect or breaks down, this causes the oxygen pressure to become too high which can poison the human body. The major oxygen poisoning encountered in aviation and space navigation occurs when oxygen pressure exceeds 176 millimeter mercury column to under one atmospheric pressure.

### 3. Temperature Environment

In the areas of atmospheric temperature and meteorological conditions, it is possible both in aviation and space navigation to encounter complex temperature changes from low temperatures to high temperatures. Besides atmospheric and meteorological

conditions, it is also possible to encounter a particular type of temperature condition. For example, because an aircraft in high speed flight has air friction, there is produced high temperature. During spaceship takeoff and return, when extremely high speeds are used to penetrate the dense atmospheric layer, this can also produce high temperatures because of air friction. Even though a series of radiator and heat insulation measures were used in construction technology, it was still difficult to avoid encountering a fixed level of high temperature. When the temperature regulation system of an aircraft or spaceship breaks down, this can be even more serious. When a spaceship is in flight, outside the atmospheric layer, because there is very little surrounding air, heat convection seems to be non-existent. Yet, when one side of the spaceship is in the sunshine, temperature can rise over 100 degrees and when one side has the earth's shadow temperature can lower to minus several ten degrees. Aside from this, if the pilots or astronauts because of an accident or bad landing put down in the north or south poles, in a torrid zone or in the ocean, they will then be able to encounter earth conditions of low or high temperatures.

Generally, it is possible in aviation and space navigation to encounter low temperatures of minus several tens of degrees to high temperatures of several hundred degrees above zero. The environmental temperature change range is quite broad and to protect man's safety and flight capabilities, it is necessary to adopt appropriate safeguard measures against these temperature environments.

#### 4. Radiation Environment

Cosmic space ionization radiation is a dangerous element to the human body. There are three major origins of cosmic radiation: (1) that from the sun is called solar cosmic radiation; (2) radiation from each direction of the Milky Way system (actually vast outer space) is called Milky Way cosmic radiation; (3) from the earth's radiation zone (inner radiation zone and outer radiation zone).

Aside from ionization radiation, the sun also regularly emits various types of non-ionization electromagnetic radiation, from ultraviolet rays to visible light, infrared rays and various different frequency electromagnetic waves. The strength of solar electromagnetic radiation can reach a level strong enough to harm the human body and therefore it is necessary to pay attention to the harm of ultraviolet ray, visible light and infrared ray electromagnetic radiation on the human body and adopt appropriate safeguard measures. Besides solar electromagnetic radiation, because of the expanded use of laser, infrared and microwave technology in recent years, the problem of the influence and safeguarding of electromagnetic radiation on the human body has become a topic of concern.

#### 5. Cabin Environmental Pollution and Medical Safeguards

High altitude aircraft and spaceship flight both use airtight cabins to guarantee bodily safety. The problem of environmental pollution on the inside of airtight cabins has also become a special environmental condition. There are three major reasons for pollution

inside aircraft and spaceship cabins: (1) from the outside environment such as ozone; (2) from the spaceship's power devices such as the gas pollution created by the flame-out device, the fuel and spent gas pollution of the aircraft and spaceship power devices, the pollutants sent forth from the coating and rubber, the pollutants emitted from the electronic devices and the dust and germs inside the cabin; (3) from human body pollution such as exhaled carbon dioxide and carbon monoxide, the stench of perspiration and excrement and germ pollution.

### CHAPTER THREE

#### GENERAL LAWS OF AVIATION AND SPACE NAVIGATION

##### ENVIRONMENTAL EFFECTS ON THE HUMAN BODY

###### Section One - Preface

In the last chapter, we described the special qualities and features of the aviation and space navigation environment. The effects of these environmental conditions on the human body are actually brought about within various complex relations. The so-called action of a single condition is only the most outstanding manifestation in a certain dynamic process. Because of this, the physiological changes and pathological process of the human body in space navigation as well as their reasons and reaction mechanisms should all be concretely analyzed. Generally speaking, the effects of these particular environmental conditions on the human body are conditioned by the following factors: (1) the qualities and composition of the environmental factors; (2) the functioning state of the organism at the time; (3) man's subjective dynamic role. Below we will first discuss the qualities and composition of the environmental factors.

###### Section Two - Quality and Composition Characteristics of Environmental Effects

From the point of view of materiality, some of the qualities of aviation and space navigation environmental conditions are mechanical (such as overweightness), some are physical (such as



ionization radiation), some are chemical (such as gas components) and some are physiological (such as cosmic stillness). Stimulant qualities are different and the induced physiological effects are also different. For example, the influence of overweightness causes organ shifts, the blood to be static and changes in dynamics; the prominent action of ionization radiation is the destruction of certain important cells; the aim of gas components such as oxygen is to supply the needs of tissue metabolism and if there is too little or too much this can bring about bad effects.

In all environmental conditions, no matter which type of factor, if the action on the human body is not excessive, the action time is not too long, the quantity does not increase too quickly and the position and area of the action on the human body is not too concentrated, then there will be no harm. For example, ionization radiation was originally a type of harmful factor, but a small dosage is not only harmless but can also be used to cure illness. For beneficial substances such as oxygen, the absorption of too much can cause poisoning and too little can create anoxia. Such facts can be said to be true and found everywhere in aeronautical and aerospace medical science.

The relation of environmental conditions and the organism include the following several characteristics:

1. The Strength of Environmental Stimulation

Taking acceleration (overweightness) as an example, the G number represents strength. On the earth's surface, people are subject to 1 G gravitational acceleration and this is the normal

gravitational force on earth. When a person is subject to about 2 G overweightness while sitting in an aircraft or starting an automobile, the human body can totally endure this and this does not cause any great physiological effects. From 2 G upwards, the human body begins to show unhealthy reactions. By 4-5 G, people generally have impaired vision and at even higher G factor overweightness there is blackness (there is a strip of black in front of the eyes, and the person cannot see anything) and even loss of consciousness.

## 2. Action Time

Originally, certain environmental conditions did not cause harmful physiological effects but if their action time is too long, good effects can change to bad effects and even cause illness. For example, for severe cold which did not cause freezing, when exposure time is long this can cause freezing injury to the feet and hands.

## 3. Growth Rate of Action Quantity

Generally speaking, if the strength of environmental condition actions increase slowly, their physiological effects are usually weaker. However, if the growth rate is very fast, then physiological reactions can become acute. For example, when an aircraft goes up, the higher the altitude the lower the atmospheric pressure. If the aircraft does not ascend too quickly, this does not usually cause decompression sickness but if the climbing rate exceeds 1,200 meters per second this can bring about decompression sickness, for example, pains in the joints. This is caused by a too fast decompression speed.

#### 4. Position and Area of Action

This is most noticeable in the overweight effect. The longitudinal axis of overweight action on the human body is much greater than the lateral physiological influence on the human body. If the action area is excessively small and too concentrated, this can cause localized injury such as high temperature causing localized burns. However, if the action area is too great, this can cause strong reactions for the whole body and if the problem is exposure to low temperatures, this can cause freezing to stiffness.

The above mentioned mutually acting factors of environmental conditions and an organism are universal for actions in aviation and space navigation environments toward the human body. However, item "4" sometimes shows certain deviations. Generally, if the strength of the actions of environmental factors on the organism are great, the time long, the action fast and the action area large, then its influences cannot be overlooked.

Another problem of environmental condition reactions is the simultaneous action of many factors and the contradiction of the primary and secondary. It has already been pointed out previously that aviation and space navigation environments are very complex and include many factors. The majority of these factors act on the human body continuously and simultaneously and in one time phase the most outstanding are a link in a whole chain. In other words, in each moment the actions of environmental condition factors should be divided into primary and secondary. At the same time, it is also necessary to pay attention to their mutual

relations, mutual contradictions and mutual coordination. For example, light lack of oxygen decreased anti-overweight endurance, yet, under conditions of lack of oxygen, the endurance of the human body to ionization radiation was raised. Judging from this type of contradiction, lack of oxygen is still a secondary factor. This type of secondary factor causes opposite actions for the two types of different quality primary factors and it is best to say it is a secondary factor and not a primary factor. Naturally, primary factors and secondary factors can change. Motion sickness (airsickness) that occurs in aviation is a typical case. Everyone knows that aircraft vibration and bumping is the reason for airsickness. New flight student sufferers are quite numerous. However, when they hear any emergency command, airsickness usually disappears immediately. This shows that from its occupying a major position, vibration and bumping can retreat to a secondary place. After the emergency command is removed, airsickness often returns which explains that at this time the aircraft vibrations and bumping stimulation again return to a dominate position.

### Section Three General Laws of Physiological Effects

#### 1. Basic Viewpoints on Physiological Effects

Before discussing the specific phenomena and mechanisms of physiological effects, we will first introduce a few basic viewpoints.

##### 1) Organic Viewpoint

The human body is an organic whole and by means of the nervous

and body fluid regulatory system, the functions of each organ are mutually related, mutually conditioned, mutually coordinated and form a unified whole. As such, the reactions of any aviation and space navigation environmental conditions and factors on the human body always maintain a unified whole and thus the person is not subjected to harm. This is not to say that under certain given conditions the reactions of organs and systems all follow the same qualitative and quantitative patterns. On the contrary, the reactions of each organ are not only different in any given moment but some are original which is the first level of environmental factors, some are continuous which is the second and third levels induced from the first level of reactions; some are strengthened actions and some are weakened actions; some reactions are mutually coordinated and some are mutually opposed; some are excited and some are restricted. However, no matter what the organ reaction, coordinated or opposed, strengthened or weakened, their physiological tendencies are unified which is the maintenance and recovery of normal physiological functions, the preserving of relative stability of the body's internal environment and the reaching of a balanced state in the actions of each organ and system.

## 2) Generality and Particularity

The qualitative and quantitative differences of each organ reaction mentioned above are manifestations of their particularities. Moreover, the tendency of their actions tend towards maintaining a balanced state in the body's internal environment

and function. This is their generality. Generality and particularity can hold a great deal of meaning in the field of particular environmental medicine such as in individual differences (particularity) and colony averages (generality). The larger part of this book represents the average of the colony. What we want to call attention to here is that the colony average does not represent the parameter of the individual and therefore, when using it in concrete situations, we cannot overlook individual differences such as the functioning state of an individual at a given time and the subjective activities of an individual.

### 3) Internal and External Causes

"External causes are the conditions of change, internal causes are the basis of change and external causes become operative through internal causes". In the field of aeronautical and aerospace medical science, environmental conditions are external causes while the functioning state (including each organ) of the body's internal environment and functioning and subjective flexibility and initiative make up the internal causes. The actions of external environmental conditions on the human body are realized through the functions of the body's internal environment and each organ and system. Whatever the functioning state at the time and whether or not subjective flexibility and initiative play a role, it can greatly change the effects of external causes. For example, acclimation, training and exercise can raise a person's endurance to certain harmful environmental factors and this results in raising the body's functioning state and subjective

flexibility. It cannot be denied that the capacity of the human body to overcome particular environmental harm has fixed limitations. People cannot endure surpassing these fixed limitations with the result of the development of sickness or harm to the organs. Even if it is thus, external causes always become operative through internal causes.

#### 11. Qualities and Characteristics of Physiological Effects

The reactions of the human body towards particular aviation and space navigation environmental conditions is extremely complex and the consequences are also varied. The various patterns of physiological effects can be divided and discussed in three categories.

##### 1. Light and Middle Degree Harmful Environmental Effects

So-called light and middle degree environmental effects point to the effects of the human body's ability to compensate, adapt and acclimate. If the human body can produce permanent compensation, adaptation and acclimation it is necessary that:

- 1) the human body have time to develop compensation and adaptation;
- 2) the external environmental conditions continue to exist or be able to have repeated action;
- 3) the body's functioning state be normal.

If we use low pressure lack of oxygen as an example, the organism's compensation action is multifaceted, some are very fast or occur immediately and some only act after a specific amount of time. If the amount of breath taken in the lungs and cardiac output are increased there is a

fast reaction and if the red blood cells and haemoglobin are increased then it is slower so that the lungs' abilities are thoroughly improved and there is economizing of oxygen in metabolism, when it is necessary to have a longer period of time. It is necessary to recognize that for the environmental conditions most people can adapt to, there is a minority of people who cannot. Using the example of low pressure lack of oxygen again, for some people, no matter how long they live in a high mountain or plateau area, they still show indications of sickness. For these people, most important is that the internal causes have defects, for example, congenital sickle cell anemia. There is also a very small minority of people who because their adaptation was vigorous, produced "many symptoms of adaptation sickness". This is because in the adaptation process the chain reaction of nerve → anterior pituitary → adrenal cortex too often caused the exhaustion of cortex hormones.

## 2. Effects on Heavy Degree Harmful Environments

So-called heavy degree indicates break out with great force and the applied force is also very great. This type of effect often causes serious harm to the extent of threatening life and the human body has no chance to regulate or compensate. We can only take protective measures beforehand for this type of situation. For example, situations in which an airtight cabin suddenly leaks gas and causes explosive decompression or the surgical wounds caused by aircraft collisions are very dangerous. For the most part, these types of injuries occur on unexpected occasions and are not too



likely to occur in most aircraft and spaceships.

### 3. Compensation, Adaptation and Acclimation

Compensation, adaptation and acclimation are important types of physiological safeguard mechanisms for the human body to deal with particular environmental factors. They are limited to actions that are not too strong or violent and do not at one time cause harm to the organism. Because compensation, adaptation and acclimation require a specific amount of time, when the organism has already been severely injured, only emergency clinical treatment and cure can be used. Compensation mechanisms differ in accordance with the various stimulated factors and for the most part involve the transforming of many physiological functions. This is the basis of adaptation. When an organism reaches the adaptation stage of a harmful environment, the previous harmful effect will not occur again. So-called acclimation is the development of adaptation to its highest stage wherein people will not again, subjectively or objectively, have harmful feelings and reactions toward a harmful environment.

## PART TWO

### MEDICAL PROBLEMS OF GRAVITATIONAL CHANGES AND POWERED FLIGHT

#### General Remarks

When an aircraft is in aerial flight, it can be divided into two types of situations. One type draws support from engine thrust which is called powered flight. The other type is when there is no engine thrust and there is only support from the aircraft's inertia. This is called powerless flight. Powered flight can cause bumping, vibration, oscillation, turning somersaults and noise and overweightness can be produced by the motions of acceleration and deceleration. The relation of the qualities of these factors and an organism have already been briefly described in chapter two. This part will discuss the qualities of particular conditions under three major groups.

The first group is related to gravitational changes. For example, overweightness is a large increase in gravitational force; impact is a type of overweightness wherein the time is very short ( $< 0.3$  seconds), the numerical value is extremely large and the overweight growth rate is very high; vibration is a type of generalized overweightness in which the numerical value and directional period often change repeatedly. All of these belong to the changes of gravitational force, that is, overweightness.

The second group is related to angular acceleration. For

example, when turning or performing a somersault there is angular speed and oscillation are the angular acceleration in which the numerical value and directional period often change repeatedly. Angular acceleration is also a type of gravitational change, but aside from the larger overweightness created in high speed turns and somersaults, the physiological effects of most angular acceleration are related to the reactions of the vestibular organ and the vestibule-autonomic nervous system reactions and motion sickness caused by the acceleration. Because the physiological effects are caused by gravitational changes from angular acceleration, they are in a secondary position. Therefore, there are physiological differences between the conditions of the first and second groups.

The third group is noise produced by air vibration. This air vibration effects the human body.

In aviation and space navigation, there can also be weightlessness and low gravity, for example, the weightlessness after a spaceship enters an orbit around the earth and low gravity encountered after landing on a celestial body (for example, the moon). Although they are not produced from powered flight, yet because all belong to the category of gravitational change, qualitatively, they belong to the same category as the conditions of the first group. For convenience of narration, we also placed it in this part of the book on powered flight.

Generally speaking, in this part of the book, we investigated the possible gravity change conditions encountered in aviation and space navigation as well as the possible environmental conditions

encountered in powered flight and their influences on the human body and safeguard methods against them.

CHAPTER FOUR  
INJURY AND PROTECTION OF OVERWEIGHTNESS \*

Section One - Preface

1. Attraction Force Acceleration, Acceleration, Gravitational Force, Overweightness

When any aircraft is in aerial flight it is always the result of the action of force and the changes of this type of force necessarily become the responsibility of the controllers and passengers. Most aviation and space navigation is variable motion and the path of motion is the result of the combined force action of various forces (gravitational force/ attraction force, lift force, the pulling force/thrust of an engine). The changes of force can have physiological effects on people.

Although the earth moves at a uniform speed of 24.9 kilometers per minute, people on the earth's surface do not suffer any feelings of discomfort. This is because uniform speed has no changes of force and does not cause reactions in the organism. In most situations, changes in force can cause stimulation and reactions in the organism. This is one physiological law of the effect of outside forces on the human body.

When in flight, because of speed and course changes the reacting forces of directional reversals and large and small phases can produce effects in the organism, thus there appear shifts, vibrations and extruding of the tissues. Physiologically, organ

\* Read as- excess acceleration- "G's"

Positive overweightness= + G's

Negative overweightness= - G's (38)

tissue weight changes appear first which are the increases and decreases of gravity.

Because of the earth's attraction the human body can also produce specific gravitational force (weight). On a latitude of 45°, the gravitational force produced by the earth's attraction causes the acceleration of a substance formed from the descent (the earth's attraction acceleration) to be -

$$G = 9.8 \text{ meters/second}^2$$

The above formula shows that the gravitational unit G is indicated by its produced acceleration.

If the human body is influenced by powered flight and causes the gravitational force (the normal weight on the earth), the normal state of tissue organs to produce changes, when the numerical value of this type of change is greater than one G it is called overweightness and when it is smaller than one G it is called low weight. If G is equal to 0, this is called weightlessness. Because of this, the word overweight is a physiological term. Overweight points to a specific time when the human body is under outside force and the tissue organs are in a gravitational state greater than its normal state on the earth's surface. The physiological process which is manifested from the effect of the force on the body is the so-called overweight physiological state. The measurement of weight of this type of state, besides some indices in medicine and physiology (such as heart rate and breathing changes), is still commonly used to indicate the size of the gravitational acceleration of G.

The physiological effects of overweightness are conditioned by the following physical factors: the size of the outside force load, the transformation rate of the load (the speed of the increases and decreases of G), the length of action time and the direction of the force's action. It can be said that the human body's reaction to overweightness depends mainly on the sizes and changes of the above mentioned various physical factors.

The gravitational force acceleration of G cannot only be used to weigh the mechanical state of human body organs - overweightness, low weight and weightlessness but it can also be used to measure the size of the action of aircraft speed changes on the human body. This is also saying that it can be used to weigh the size of the outside force load created on the bodies of operators and passengers in powered flight. As for the human body load, when the outside force load produced in powered flight is under 3 G, it can be called light overweightness, when the load is 3-8 G, it can be called medium overweightness, and when the load is above 8 G, it can be called heavy overweightness.

Most powered flights are variable motion which is also increased speed or decreased speed motion. The increases and decreases of flight speed are in essence a type of acceleration motion. Increased speed is positive directional acceleration and decreased speed is reverse directional acceleration.

The changes in flight speed not only change the action of the outside force load on the flight personnel but at the same time also change the position of the human body in space. If an aircraft

carries a human body to a new celestial body, the organism's gravitational force will then change according to the celestial body's attraction changes. This is a direct reason for the changing of a person's normal mechanical state when on the earth's surface. Because of this, when analyzing the human body mechanical effects of leaving earth and entering an outer space environment, besides needing to understand the actions of powered flight acceleration, we should also look at the celestial body's attraction changes caused by the environmental shifts of the celestial body. This is also an important reason for the change of a person's normal mechanical state.

## 2. Aircraft and Spaceship Overweightness

Overweightness can be encountered in everyday life. For example, when a fast car takes off suddenly the passenger feels his body is being pressed backwards and when a car comes to a sudden stop he feels his body is charging forward. These are all human body reactions caused by overweightness. However, in daily life on the earth's surface, the numerical value of overweight feelings is relatively small and the time is short. People do not feel unwell and therefore do not pay attention to it. Yet, in aviation and space navigation, the numerical value encountered is relatively high and overweight time is longer. This type of overweightness causes people to feel quite badly and can even cause injury. Therefore, in aviation and space navigation, overweightness is a problem worthy of close attention.



When an aircraft is in straight flight, if there are speed changes, then overweightness is produced from the existing acceleration or deceleration. For example, when taking off, overweightness is produced from acceleration and when landing, overweightness is produced from deceleration. When a fighter plane is performing stunt flying (such as dives and climbs), 2-4 G overweightness can be produced and can reach as high as 8-9 G. However, the time in the highest limit is very short - otherwise a person cannot endure it. Generally, overweightness in transport planes and civil aircraft occurs mainly during takeoff and landing and the numerical value is usually in the area of 2-3 G. Most people can endure this type of overweightness and therefore overweightness is not a serious problem in civil aviation.

When spaceships are in powered flight, for example, when they take off and return to earth and enter a dense atmosphere, overweightness occurs in accelerated and decelerated flight. If the spaceship uses a multistage rocket takeoff, after each rocket stage is launched, the overweight numerical value gradually increases and when nearing burn out it reaches peak value. After the rocket burns out, overweightness suddenly drops and then ignition of the second rocket stage begins and again overweightness gradually increases. This is repeated until the third and fourth stages. Therefore, if a multistage rocket is used to launch a spaceship, it is often necessary to go through several sawtooth overweight increase and decrease processes during takeoff. The peak value of overweightness is then limited to the 6-8 G range. Chart 2-1 shows

the overweightness of a three stage rocket in the process of launching a spaceship. When a spaceship is returning into the dense atmosphere, larger overweightness occurs. This is due to the relatively large deceleration from the air resistance on the spaceship. The highest overweightness of an airship is generally controlled to 6-8 G and action time is controlled to within several tens of seconds.

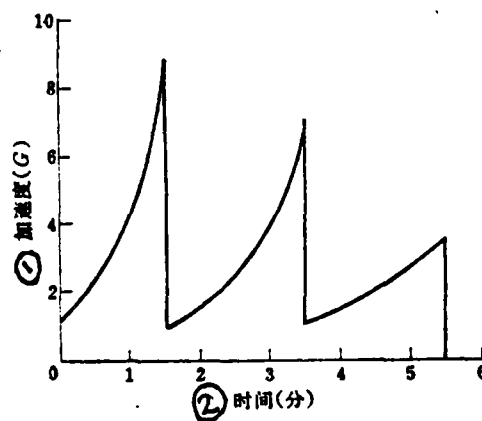


Chart 2-1 Acceleration of a Three Stage Rocket

1. Acceleration (G)
2. Time (minutes)

Besides straight acceleration, when aircraft or spaceships make large angle turns or circles, overweightness is produced by centrifugal force and is called ray overweightness. Transport planes and civil aircraft make turns very slowly and the centrifugal force

produced is not large so that it very rarely exceeds 2 G. When fighter planes perform spiral stunts, overweightness can reach 2-4 G. If the position control system of a spaceship is normal, its turning and circling centrifugal force is not very large. Only when the position control system is abnormal is there the possibility of falling into a high speed spin wherein the centrifugal force reaches to more than several G.

## Section Two - Physiological Influences of Overweightness

The influence of overweightness on the human body is a type of inertial reaction mechanical force. It can cause relaxed and suspended organ shifts, soft tissues to be crushed, blood to undergo kinetic changes, the body to shift, influence limb movement and arouse a series of reflex and compensations reactions.

As soon as acceleration stops, the mechanical force disappears and organ, tissue and influenced body parts then quickly restore to health. If overweight strength and time do not exceed the level of the organism's injury or the body is safeguarded and overweightness stops no other illness can be produced. Overweightness as a type of mechanical force is closely related to the effects on the human body and its direction of action. For example, overweightness in the head + foot direction causes the suspended organs of the human body (such as the chest, abdomen and internal organs) to shift downwards and causes the blood to flow down to the lower half of the body. If the direction of overweightness is from the chest + back, the body's organs and blood shift from the

chest to the back. Obviously, the shift range of the former is much greater than that of the latter and therefore the influence of positive overweightness on the human body is much stronger than that of lateral and horizontal overweightness. Because overweightness in different directions have different effects on the human body, it is necessary to distinguish them.

In aeronautical and aerospace medical science, the overweightness in different directions are given different names. The names of overweightness directly precede the direction of the overweightness. For example, head → foot overweightness indicates overweightness from the head towards the feet. When a person stands on the earth's surface, the direction of the earth's attraction is the head → foot direction and therefore in aeronautical and aerospace medical science overweightness in the head → foot direction is called positive overweightness. Overweightness in the foot → head direction is called negative overweightness. These two are jointly called vertical overweightness. Chest → back and back → chest overweightness are jointly called horizontal overweightness. Left → right and right → left overweightness are jointly called lateral overweightness. Acceleration is a physics term and overweightness is a physiological term which some people in science and technology call "overload". Its significance, symbol and mutual relations are listed in table 2-1 and a figured schematic chart (chart 2-2) indicates it for easy comprehension and recall.

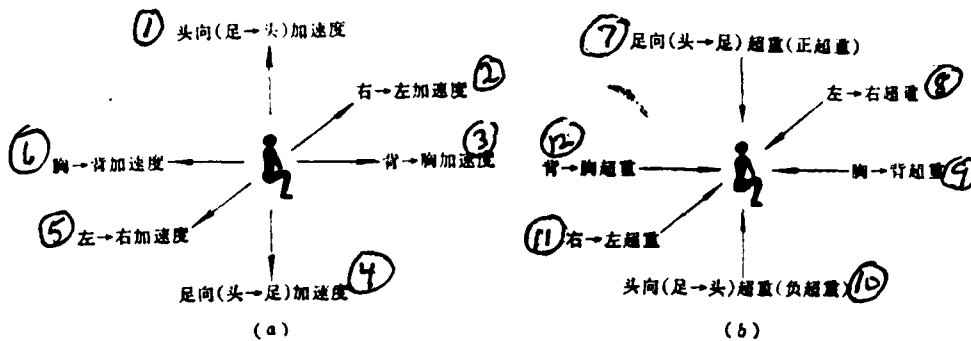


Chart 2-2

a. Acceleration direction and name

b. Overweight direction and name

1. Head direction (foot → head) acceleration
2. Right → left acceleration
3. Back → chest acceleration
4. Foot direction (head → foot) acceleration
5. Left → right acceleration
6. Chest → back acceleration
7. Foot direction (head → foot) overweightness (positive overweightness)
8. Left → right overweightness
9. Chest → back overweightness
10. Head direction (foot → head) overweightness (negative overweightness)
11. Right → left overweightness
12. Back → chest overweightness

① 加速度性质	② 加速度方向	③ 加速度名称	④ 超重名称	⑤ 生理学名称	⑥ 符号	⑦ 俗称
⑧ 直线和射线加速度(离心力)	⑨ 前向	+a <sub>17</sub> 前向加速度	⑩ 前后横向超重、仰超重	⑪ 胸→背超重	+G <sub>x</sub>	眼球凹入 ⑫ 29
	⑬ 后向	-a <sub>18</sub> 后向加速度	⑭ 前后横向超重、俯超重	⑮ 背→胸超重	-G <sub>x</sub>	眼球凸出 ⑯ 30
	⑰ 上向	+a <sub>19</sub> 上向加速度	⑱ 正超重或头→足超重		+G <sub>z</sub>	眼球下垂 ⑲ 31
	⑳ 下向	-a <sub>20</sub> 下向加速度	㉑ 负超重或足→头超重		-G <sub>z</sub>	眼球上抬 ㉒ 32
	㉓ 右向	+a <sub>21</sub> 右向加速度	㉔ 左侧超重或右→左超重		+G <sub>y</sub>	眼球向左 ㉕ 33
	㉖ 左向	-a <sub>22</sub> 左向加速度	㉗ 右侧超重或左→右超重		-G <sub>y</sub>	眼球向右 ㉘ 34
③⑤ 参看图2-2a.	③⑥ 参看图2-2b.					

Table 2-1 (Key-next page)

Table 2-1 Physics and Physiological Names of Acceleration and Overweightness

1. Acceleration properties
2. Acceleration direction
3. Acceleration name
4. Symbol
5. Common name
6. Overweight name
7. Physiological name
8. Symbol
9. Common name
10. Straight and ray acceleration (centrifugal force)
11. Forward
12. Backwards
13. Up
14. Down
15. Right
16. Left
17. Forward acceleration
18. Backwards acceleration
19. Head acceleration
20. Foot acceleration
21. Right side acceleration
22. Left side acceleration
23. Forward and back horizontal overweightness, upwards overweightness, chest → back overweightness
24. Back and forward horizontal overweightness, downward overweightness, back → chest overweightness
25. Positive overweightness or head → foot overweightness
26. Negative overweightness or foot → head overweightness
27. Left side overweightness or right → left overweightness
28. Right side overweightness or left → right overweightness
29. Concave eyeball
30. Convex eyeball
31. Downward eyeball
32. Upward eyeball
33. Eyeball toward the left
34. Eyeball toward the right
35. See chart 2-2 a
36. See chart 2-2 b

Vertical seating is most common in aircraft and thus most overweightness is in the head → foot or foot → head directions. The lying down position is most commonly used in spaceships and overweightness is mainly horizontal.

Among the effects of overweightness on the human body, the most prominent are blood kinetic reactions and suspended organ and suspended tissue shifts. Yet, following the directional and time differences in the action of overweightness, their primary and secondary positions are also different. Taking upright overweightness and negative overweightness as an example, the blood kinetic effects are usually greater than the effects of organ and tissue shifts. This is because the aorta chiefly distributes vertically and therefore the blood's up and down flow in overweight action is greater and the reaction is faster and stronger. In horizontal and lateral overweightness, because most of the distribution in the horizontal and lateral directions is in small blood vessels and has many branches, the short blood flow reactions are relatively small. Therefore, the shifts and pressure of suspended organs (especially in the thoracic cavity - the heart and lungs) occupy an important position. Aside from this, certain suspended tissues in the limbs, such as shank muscles, often suffer pain because of shifts and pressure. These influences then become important restricting factors for the endurance of horizontal overweightness.

In overweight action time, because the blood flows relatively fast in the initial period of overweightness, the effect caused by the blood kinetic reaction appears early and then follows the effects of suspended organ shifts. Human body compensation reactions occur relatively late and generally require several seconds to over ten seconds to appear. Some even require a longer period of time and only after repeated actions do they appear.

## I. Physiological Effects of Positive Overweightness

The physiological effects of positive overweightness appear mainly in kinetic changes in the blood, imbalance in the functioning of heart blood vessels, changes in respiratory movement and functions and nervous system and internal organ functions. Among these, blood circulation reactions are the most outstanding.

### 1. Blood Kinetic Changes and Their Physiological Effects

#### (1) Loss of Blood Distribution Equilibrium in the Upper and Lower Body

When an organism has upright overweightness, blood weight naturally increases drastically which causes blood distribution in the upper and lower body to lose normalcy. For example, when overweightness reaches 7 G, the blood seems as heavy as molten iron and when it reaches 8-10 G, the blood seems as heavy as mercury. According to the direction of the overweight action, increases in blood weight cause the peripheral blood vessels to fall to the lower half of the body, cause blood pressure in the lower half of the body to rise and blood capacity to increase. At the same time, this creates a deficiency of blood in the upper half of the body and the supply of blood to certain important organs (the brain, eyes etc.) is insufficient. As a result, the symptoms of pale facial coloring, uncomfortable pain and sight deficiency appear.

After the human body is subjected to 2.5 - 4.0 G positive overweightness for 15 seconds, the average growth of blood capacity in the lower limbs is 30-40 milliliters and the pressure of the great saphenous veins increases 40-60 millimeters on the mercury column. When blackened vision occurs the leg tissues increase 1.3 milliliter volume per 100 milliliters. If blood



pressure in an upper arm artery has a rise in compensation and the heart beat becomes slower, it is only necessary to have the overweightness to continue to exist and the blood capacity will continue to increase until it arrives at a specific numerical value. Increases in the lower limb blood capacity forms a linear relationship with the overweight value. For each rise of 1 G in common positive overweightness, the average shank volume increase is about 30-150 milliliters. The pattern of finger volume changes is more or less the same as shank volume changes but of course the absolute value is much smaller. These facts imply that the changes of volume in suspended parts of the lower and upper limbs are mainly caused by the changes of blood statics and kinetics.

#### (2) Insufficient Blood Supply to the Brain and Eyes

Positive overweightness forces the volume of the blood to drop to the lower half of the body and this brings on anemia in the upper half of the body and in its organs. The brain and visual organs are especially sensitive to this type of condition. When overweightness reaches 3.5-5 G in a healthy young person, there can be a serious shortage of blood to the retina which produces symptoms of grey or blackened vision. Thus, for trained fighter pilots, when the average reaches 6 G, they experience grey or blackened vision. So-called grey vision indicates that the functioning of the periphery of the retina is lost but the center of the retina still functions. At this time, the person feels that there is grey before their eyes and at the same time their peripheral

vision is lost. If the overweight value further increases, vision goes from grey to black and temporarily there is complete loss of vision. There is the feeling that there is a strip of black before the eyes and the person cannot see anything. Grey and blackened vision are the effects of overweightness on the human body which has reached a serious level. At this time, the ability to operate an aircraft has been destroyed. In aeronautical and aerospace medical science, grey and blackened vision are often used as a norm for people's limit of endurance towards positive overweightness.

Blackened vision is not only a sign of vision loss but at the same time it also shows that when the human body's highest nerve center (the brain) is in a state of blood deficiency, this is a prelude to the functional impairment of the central nervous system. If after blackened vision occurs overweightness increases or is maintained, then it is difficult to avoid dizziness, obscured consciousness and even loss of consciousness. If consciousness is not lost for a long time, then consciousness and vision can be quickly restored after overweightness stops or its numerical value drops and there will be no after effects. On the contrary, if consciousness is lost for a long period of time, this can cause irreversible damage to the brain and there is the possibility of a remaining after effect.

The occurrence of vision impairment and an insufficient supply of blood to the retina are directly related and this has already been proven in laboratory experiments. For the close

relationship of lack of blood in the eyes and vision impairment caused by overweightness, see charts 2-3 and 2-4.

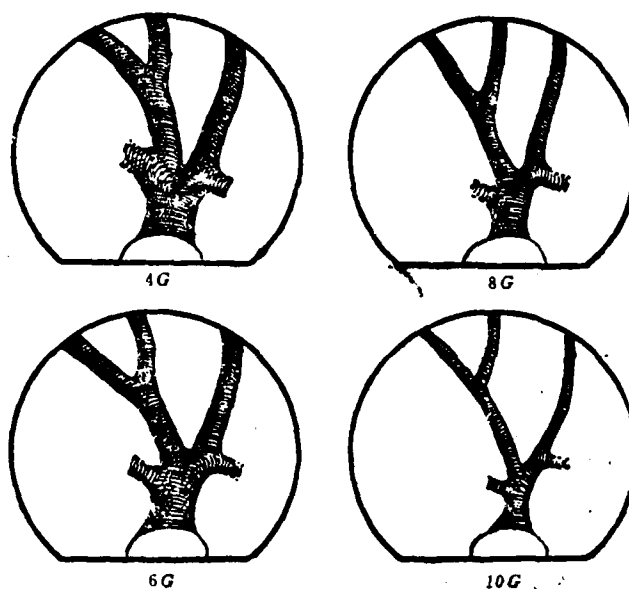


Chart 2-3 Schematic Drawing of a Blood Vessel in the Retina Shrinking According to the Increases of the Overweight Numerical Value

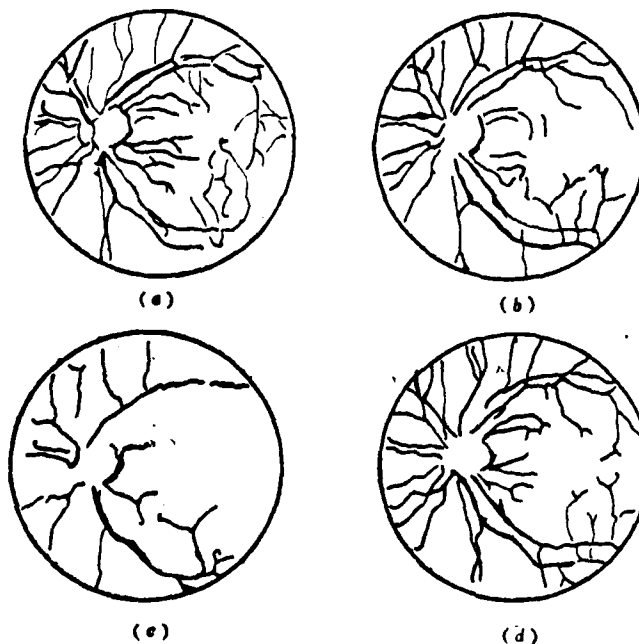


Chart 2-4 (Key, next page)

Chart 2-4 Changes of a Subject's Retina Blood Vessels When There is Overweightness

- a. Prior to acceleration
- b. The first period of 4-5 G (+ G<sub>2</sub>)
- c. Grey vision occurs
- d. After acceleration is stopped

(3) Blood or Body Fluid Seepage

Positive overweightness causes blood to flow down to the lower half of the body and forces certain tissues to amass too much blood in this region of the body. Sometimes blood causes lateral pressure on the walls of blood vessels to continually increase to a specific level. This can bring about extravasted blood or splits in tiny blood vessels which produces redness and swelling or purple spots especially at the bends of the body and in pressure areas.

If positive overweightness is excessively large and is maintained for a long period of time, then because lower limb vein pressure increases, blood flow in veins returning to the heart is blocked. This causes blood circulation in the tiny blood vessels of the lower limbs to be obstructed. At this time, there is an increase in the internal pressure of arterial capillaries, plasma seeps into the tissues, there are splits in the capillaries and ecchymosis is produced. At the same time as this, the flow of returning blood in the veins is blocked, the inner pressure in the venous capillaries increases, the return flow of the body fluid in the cells is blocked and this causes body fluid stasis and tissue swelling in the lower limbs. Because the internal pressure of the tissues has increased and produced extruding, there is

the possibility of limb or hanging position pain and expansion of surface veins.

## 2. Heart Blood Vessel Reactions

Overweightness causes the weight of circulating blood in the vessels to increase and aside from bringing about the above mentioned series of reactions, it can also cause changes in heart blood vessel functioning and produce compensating reactions.

Positive overweightness causes blood to flow to the lower half of the body, brings about a decrease in the flow of blood returning to the heart and creates a lack of blood in the heart and cardiac muscle. This then brings about a decrease in heart load capacity and an increase in blood weight further causes an increase in heart load. This forms two levels of constriction for the heart which seriously effects its functioning and notably decreases heart output. It has been experimentally proven that when less than 2.5 G positive overweightness last for a long time, heart output decreases to only 60% of normal rest time. When positive overweightness continually increases, this can cause an insufficient supply of blood to the heart coronary and a decrease in the amount of blood returning to the heart. At the same time, it can also cause the heart beat to become faster and the load of the heart to become even heavier. If, at this moment, the overweightness is not eliminated or lightened this can cause rise to cardiac contraction weakness, lowering of blood pressure and can even cause heart injury and the heart beat to suddenly stop.

The reaction of the heart to overweightness can also be shown on an electrocardiogram. For example, in the sinus tachycardia the P-R and Q-T segment shortens, the P wave drops, the S wave deepens and the T wave levels or inverts. The QRS wave group time is extended. If there is an accompanying T wave reversal at the same time as the S-T segment drop, this signifies an insufficient supply of blood to the coronary artery which can cause the possibility of lack of oxygen to the cardiac muscle and the danger of heart failure. However, the cardiac muscle has a specific oxygen reserve so that there is no serious lack of oxygen to the cardiac muscle within a few seconds. This is to say that generally, a few seconds of overweightness does not cause the above mentioned symptoms.

Because positive overweightness causes a large amount of blood to shift to the lower part of the body, the blood pressure in places above the level of the heart (such as the carotid artery) drops and blood pressure in places below the heart (such as the femoral artery) rises. Blood pressure of the brachial artery is above the level of the heart. When overweightness reaches a specific numerical value, brachial artery blood pressure drops rapidly and very quickly reaches the lowest point. At this time, even though overweightness is still maintained at a constant value, brachial artery blood pressure begins to rise again because of the compensation reaction. After overweightness stops, blood pressure often rises to a level higher than the original. For the effects of overweightness on heart rate, blood pressure and ear non-transparency see chart 2-5.

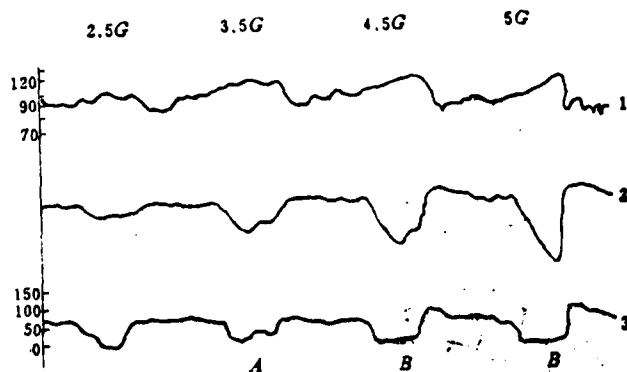


Chart 2-5 The Action of Foot → Head Overweightness on Vision, Heart Rate and Head Area Circulation

1. Heart rate (times/minute)
2. Ear non-transparency
3. Head area artery blood pressure (millimeters on the mercury column)

Below: A. Loss of peripheral vision (grey vision)

B. Peripheral and center vision completely lost (blackened vision)

Arterial pressure gradually rises when overweightness has not yet stopped. This is the result of the pressor reflex of the carotid sinus and aortic sinus. Chart 2-6 is a mechanical diagram of this type of nerve reflex regulation. In the main artery walls there are abundant pressure receptors. When blood pressure rises this arouses the depressor reflex and when blood pressure falls to a critical level this arouses the pressor reflex. The pressor reflex includes strengthening and speeding up palpitations and peripheral small artery spasms increase resistance which raises artery pressure. This type of compensation reaction prevents the

dropping of the blood pressure and it is gradually restored to its original level. The reflexive and conscious tightening of the abdomen also helps the blood pressure to rise. Experienced fighter pilots have a higher endurance to overweightness. This is not only because their reflex compensation function is good but it is also because their subjective activity is higher which enables them to regulate body position and muscle tension and thus overcome the decrease in blood pressure.

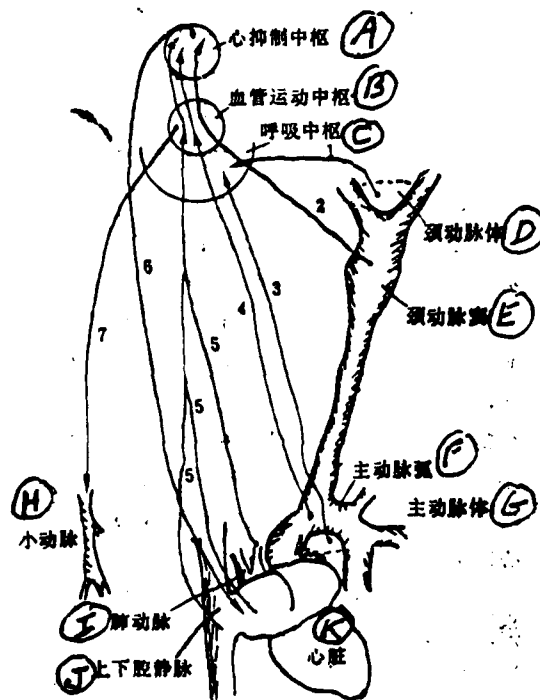


Chart 2-6 (Key, next page)



Chart 2-6 Schematic Drawing of One Ring of Heart Blood Vessel  
Self Regulation

- A. Heart inhibitory center
- B. Blood vessel motor center
- C. Respiratory center
- D. Carotid arterial body
- E. Carotid sinus
- F. Aortal arc
- G. Aortal body
- H. Arteriole
- I. Pulmonary artery
- J. Upper and lower cavity veins
- K. Heart

1 and 3 separately represent the carotid artery and aortal nerve fiber transmission of an impulse, caused by lack of oxygen, to the cerebral respiration center to regulate respiration; 2 and 4 separately represent the sinus nerve and arc nerve transmission of an impulse, caused by a drastic rise (or fall) in blood pressure, to the blood vessel motor center and heart inhibitory center. It passes through the pneumogastric nerve (6) and main vessel nerve (7) which causes the heart rate to slow down and blood pressure to decrease (blood pressure decrease causes the opposite action). Rise in blood pressure in the pulmonary artery, right atrium and upper and lower cavity veins causes the heart to palpitate quickly and vein pressure to rise.

The level of the blood pressure drop is related to the level of the separated heart. Concretely speaking, at eye level with each increase of 1 G, the average systolic pressure decrease is 32 millimeters on the mercury column and the diastolic pressure decrease is 20 millimeters on the mercury column. The lowest blood pressure appears in a continuous 7 seconds of overweightness and after this it gradually rises. Generally speaking, when eye level blood pressure is in a 50 millimeter mercury column, vision is normal and no harm is sustained. On the contrary, when systolic pressure drops to under 30 millimeters on the mercury column, this can cause lower power of vision or blackened vision. When it drops to below 20 millimeters on the mercury column, vision is completely lost. At heart level, with each increase of 1 G overweightness,

the average blood pressure decrease is 4 millimeters on the mercury column and the diastolic pressure does not change. After overweightness is stopped, heart level systolic pressure rises and this rise can reach to more than 20-70 millimeters on the mercury column higher than before the overweightness.

Under positive overweightness, the organism's compensation reaction causes the heart rate to quicken, heart contractions to become stronger and arterial blood pressure to rise. These compensation reactions generally require a 4-7 second latent period. Under 3 G positive overweightness, the average heart rate is 120-130 times/minute, when it is 4 G the average rate is 130-150 times/minute, when it is 5.8 G the rate is 155 times/minute, when it is 6.2 G the rate is 160 times/minute, when it is 7-9 G the rate is 160-180 times/minute and at even higher overweightness the rate is close to collapsing. This is also to say that stronger heart contraction reactions generally only occur when overweightness is not very high. Under positive overweightness, limb muscles become tense, peripheral blood vessels of the limbs contract and the blood vessel contractions of the lower limb blood gathered area are even more intense. It can be inferred from this that the reflex reactions caused by the blood vessel and muscle receptor input signals give rise to important action in the above mentioned heart blood vessel compensation reactions.

To sum up, the entire heart blood vessel reaction can roughly be divided into four phases.

The first is the latent phase. Many physiological imbalance

short, it is possible that the third and fourth phases will not occur. If the overweight value is excessively high and growth rate very fast it is possible that the third phase will not occur but rather directly enter the fourth phase. For example, if the fourth phase extends very long, it is possible that after overweightness stops the organism will have after effects. Sometimes after the third phase begins, overweightness stops and then certain physiological reactions continue for some time and are regained later. This is the so-called after reaction.

### 3. Respiratory Reactions

When a person is under positive overweightness, the lung area bangs down and there is extruding of the diaphragm muscle which causes respiratory difficulty. Its main feature is the increase of the inhaled air/exhaled air ratio. When positive overweightness reaches to over 4-5 G respiration becomes very irregular which is manifested in slow and weak inhaling, forced exhaling and even temporary respiratory stoppage. Some people increase their respiration rate and their respiration depth becomes shallow. Because of increases in respiration rate and greater humidity, the number of breaths taken by the lungs increases. At 5 G, lung breathing is about 250% under normal weight. However, after overweightness continues for 5-10 minutes, lung breathing then tends to become normal.

Another manifestation of respiratory reactions is an increase in the amount of oxygen consumed and a decrease in the

and compensation reactions do not occur as soon as overweightness begins but rather they only begin to occur after a latent phase of 4-7 seconds.

The second is the circulation blockage development phase. At this time, the heart rate quickens, heart output decreases, blood pressure drops, ear artery pulsation gradually becomes smaller and finally disappears, and lower limb volume gradually enlarges. The longer the overweight numerical value, the longer the continuous time and the more serious the circulation blockage.

The third is the compensation reaction phase. The previously mentioned heart blood vessel reaction which stimulated the blood vessel and muscle receptors and was caused by overweightness, reflexively aroused the organism to produce a series of compensation reactions, blocked the continuous development of these imbalance factors and improved the functioning state of the organism. Thus, there was a gradual restoration of the heart rate, the number of heartbeats gradually increased, blood pressure rose and the ear artery resumed a strong pulse.

The fourth is the compensation incapacity phase. When the overweight value is excessively large or the continuous time is very long, the human body finds this difficult to bear and becomes incapacitated. Thus, blood pressure continues to drop and finally collapses and the heart rate is too fast or heart rhythm is abnormal until palpitations stop and the person dies.

The above four phases are not absolute and in reality have variations. For example, overweight action time varies the

amount of carbon dioxide exhaled. When positive overweightness reaches 2 G, lung activity decreases about 5% and at 3 G it decreases about 16%. The respiratory quotient increases. For example, when positive overweightness is increased from 4 G to 6 G, oxygen intake increases 280 milliliters/minute to 380 milliliters/minute and the respiratory quotient increases close to 1. When positive overweightness is 4 G, the artery blood oxygen degree of saturation is about 90% of its normal state. When positive overweightness occurs, oxygen intake and lung breathing while carrying out physical movements is lower than normal. At the same time, respiration tract obstruction increases and respiration becomes increasingly difficult.

Positive overweightness causes changes in blood distribution in the lungs, the lower part of the lungs fill with blood and there is a deficiency of blood in the upper half. When in a normal standing position, the blood flow proportion of the lower half and upper half is 2.7:1 and when under 2 G overweightness it is 5.9:1. If overweightness further increases, there is a peak lack of blood in the upper half of the lungs. The changes in the relationship of lung volume and intrapulmonic pressure under positive overweightness are shown in chart 2-7. The chart shows that when overweightness is 3 G, intrapulmonic pressure increases and lung volume becomes smaller.

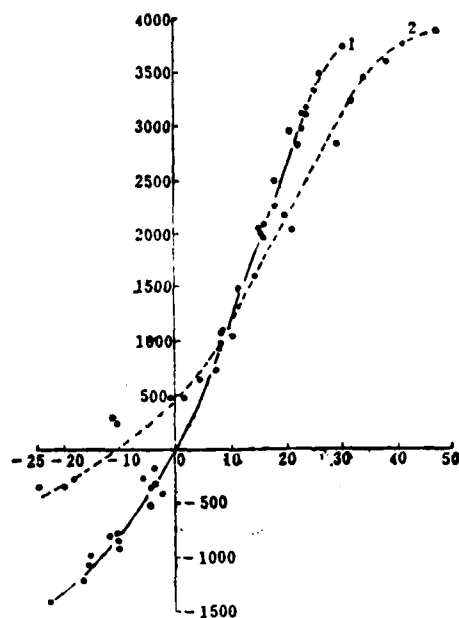


Chart 2-7 Thoracic Wall Relaxation Pressure at 1 G and 3 G

Longitudinal coordinate - lung volume (milliliters); horizontal coordinate - intrapulmonic pressure (centimeters in water column); line 1 is 1 G; line 2 is 3 G.

Without a doubt, intrapulmonic blood distribution caused by positive overweightness is uneven, pulmonary circulation is obstructed and pulmonary tissue elasticity is limited. These all are basic factors which cause abnormalities in external respiration. The far separated organs, especially the reflex actions of the circulation system and intrapulmonic receptors, are the physiological basis for regulating respiratory abnormalities. Overweightness (positive) causes the respiration rate to rise and the amount of air intake to increase. Actually, this is a type of compensation

reaction. This type of compensation reaction requires a latent phase of more than 6-10 seconds and after overweightness is finished, 10-15 minutes more are required for recovery.

#### 4. The Effects on Motor Organs

Positive overweightness causes related muscles and suspended areas to increase in weight, drop in pressure and activity to be limited. The drawn out reflex of the receptors in the motor organs causes muscle tension to increase and even the feeling of pain. When positive overweightness is 3-5 G the head cannot be lifted up and it is difficult to raise the four limbs. The cheeks, lips and lower jaw hang down and spasms and pain in the gastrocnemius are possible. After relatively high overweightness, this pain can continue for several days. An electrogram of the muscle showed that the amplitude became larger and motor units increased. The strengthening of muscle capability was beneficial to pressure of the peripheral blood vessels which forced the blood to flow back into the heart. This is also one of the organism's compensation reactions.

#### 5. The Effects on Internal Organs

Positive overweightness causes the abdominal cavity to hang and internal organ tenesmus. The digestive tract is pulled by the weight which causes nausea and an increase in rectal secretion. At this time, intestinal peristalsis is stronger and periodic pain can occur in the abdomen. When positive overweightness is relatively great, a drastic increase in otoconial gravity and pressure on

its lower tissues can cause light oedema and bleeding in the otoconial organ.

#### 6. Cerebral Function Changes - the Electroencephalogram

The compensation reactions of the human body are controlled to a very great degree by the central nervous system. One of the after effects of an overweight value increase is cerebral anemia. This causes large or small obstruction of the functioning of the central nervous system. Changes related to sensory perception and flight capability will be introduced in a later chapter. Here we will briefly discuss the reactions of the electroencephalogram.

Research carried out on humans and animals has proved that positive and horizontal overweightness cause basically similar rhythm changes in the electroencephalogram. However, horizontal overweightness requires a higher overweight value to be able to bring about similar electroencephalogram changes. For the most part, the electroencephalogram changes caused by positive overweightness can be divided into four phases or traits.

The first phase shows medium increases in  $\beta$  rhythm amplitude and the  $\alpha$  rhythm and slow wave changes are not large. This phase often appears between 3-4 G positive overweightness and 5-8 G horizontal overweightness. If overweightness continues to increase at the same time as the  $\beta$  wave and non-synchronic wave increase in strength,  $\alpha$  rhythm synchronic change can be seen to follow. The spectrum and amplitude of the slow wave do not show any notable changes.

The second phase occurs under 5 G positive overweightness



and 8 G horizontal overweightness and especially when the  $\theta$  rhythm is strengthened and the  $\alpha$  rhythm is synchronized.

The third phase occurs under 6-7 G positive overweightness and 9-10 G horizontal overweightness. Its special characteristics are that the  $\alpha$  and  $\beta$  rhythms gradually decrease and are replaced by the  $\theta$  rhythm and  $\delta$  rhythms.

The fourth phase occurs under even greater overweightness and its special feature is that the electroencephalogram uses a 1-7 cycle/second slow wave. Following increases in overweightness, frequency becomes lower and lower and finally loss of consciousness occurs. At this time, the electroencephalographic wave completely disappears.

At present, we still have only a smattering of knowledge about the physiological significance of the electroencephalogram and because of this, exactly what cerebral processes the above four phases represent is still difficult to precisely explain.

#### 7. Other Physiological Effects

Besides the above mentioned physiological effects, positive overweightness can also cause an organism's metabolism to increase as well as active changes in the number of red blood cells and internal secretion. It can also bring about a lowering of skin resistance, a decrease in urine quantity and functional changes in the autonomic nervous system. These all show that the organism's reaction to positive overweightness is an organic multi-faceted chain effect.

## II. Physiological Effects of Negative Overweightness

Negative overweightness is overweightness in the foot + head direction and is equivalent to a person's head facing downwards while hanging by the feet. This type of overweightness occurs in aircraft and space ships during inverted flight, when turning somersaults and during rapid deceleration. The effects of negative overweightness on the organism can be discussed within the following areas.

### 1. Blood Circulation

Negative overweightness causes the blood to flow to the upper half of the body, blood pressure in the head to rise and blood pressure in the lower limbs to drop. For example, when negative overweightness is 3 G, carotid artery pressure rises to 80 millimeters on the mercury column, at 5.2 G, it rises to 110 millimeters and at 7 G, it rises to 200 millimeters. Beginning from 1 G, the average carotid artery pressure increase for each negative G raise is 20 millimeters on the mercury column. There is a rise in the blood pressure of the upper half of the body and after negative overweightness is finished, it still continues for about 15-20 seconds. Because there is an excess of blood flowing into the head, the head area fills with too much blood which can cause palpitations in the temple artery, scalp tenseness, headaches, swelling of the head, plumpness in the throat area and swelling in the face. The seriousness of the face area filling with blood is the hemorrhaging of blood capillaries which cause ecchymosis and brings on severe pain. Under relatively large

negative overweightness, tissue fluid in the face and neck areas can seep out from the cells which can cause dropsy of the face and neck and even form blisters. Excessive filling of blood in the conjunctiva can also cause the feelings of a foreign body or more serious cases can bring about hemorrhaging of the conjunctiva and nose.

## 2. Eye and Brain Area Hyperemia

Negative overweightness over 3-4.5 induces hyperemia in the head area, brain area and eyes which causes a person to feel that their head is swelling and is going to crack, their eyes are protruding and similar pressing feelings. When the eyeballs swell with pain, conjunctiva hyperemia can reach a level of stabbing pain and a brilliant red appears in the field of vision which is called "red vision". There is still no unified acknowledgment of the reasons for red vision. Some people think that it is caused by retina hyperemia; some people then deduce that it is because the lower eyelids shift upwards, cover the cornea and when light rays pass through the eyelid blood vessels, this produces red vision. There are also people who hypothesize that it is due to conjunctiva hemorrhaging which causes tears to become a red color and these tears are spread on the cornea.

When negative overweightness is larger and action time is longer (over several seconds), this can further cause halting movements, directional obstruction, blurriness and even loss of consciousness. Yet, generally speaking, negative overweightness which does not last long does not cause brain hemorrhaging.

When negative overweightness is relatively great, it can cause a slow wave on the electroencephalogram and after negative overweightness ends, the slow wave can continue for several seconds to several tens of seconds.

### 3. Heart Blood Vessel Reactions

When the amount of blood doubles because of negative overweightness, to maintain circulation, the heart works to accommodate this acute increase and therefore produces a specific change in its function - a two phase change in the heart rate. If negative overweightness is under 3 G, the heart rate decreases in accordance with the increase in negative overweightness. The heart rate drop is the reflex result of the pressure receptor induced by the rise in carotid artery pressure. Thus, when negative overweightness is relatively great, the heart rate increases due to the compensation functions of the organism. An electrocardiogram indicates that when a person is exposed to 3.5 G negative overweightness for 10-15 seconds, the heart rate drops 4-6 times/minute and sometimes a temporary (several seconds) stop of palpitations and heart rate irregularities can be observed. These types of symptoms increase in accordance with the increases of the overweight value. The electrocardiogram of negative overweightness seen in chart 2-8 shows the electrocardiographic changes when negative overweightness is 3-4 G. The heart pulse becomes slow because the carotid artery pressure rises which induced a type of depressor reflex. Other heart changes, whether they are due to mechanical pressure or reflex results

aroused by blood filling the head area and heart shifts, are still not completely clear. X rays showed that without a doubt the small changes and shifts of the heart outline could effect the electrocardiogram.

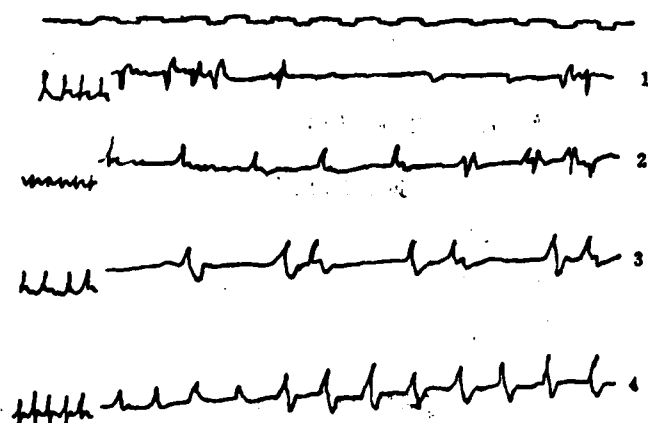


Chart 2-8 Electrocardiogram of a Dog Under Negative Overweightness ( $-G_z$ )

1. Catalectic systole
2. Extra systole
3. Slow palpitations
4. Distant PR waves

Blood pressure changes are also important signs brought about by negative overweightness. Chart 2-9 shows the arterio-venous pressure, electrocardiogram and respiration of a dog under negative overweightness. It can be seen that carotid artery pressure and venous pressure both rose, cardiac movement was slow and irregular and respiration was suspended. When carotid artery pressure rose very high it reached to 300 millimeters on the mercury column. This is because the action direction of

liquid static pressure and the kinetic direction of the heart's pumping of blood are the same and when the two are placed together, very high blood pressure is created. High blood pressure of the carotid artery increases brain blood pressure and only because of limitations by the skull and because the cranial cavity volume does not change, the blood vessels and amount of blood cannot expand unrestricted. Moreover, high pressure in the skull advances cerebral vein blood flow and thus alleviates the tendency for brain blood pressure to rise. Besides this, high arterial pressure stimulates the carotid artery sinus to arouse a depressor reflex and the heart rate to become slower thus causing the arteriovenous pressure difference in the brain area to become smaller.

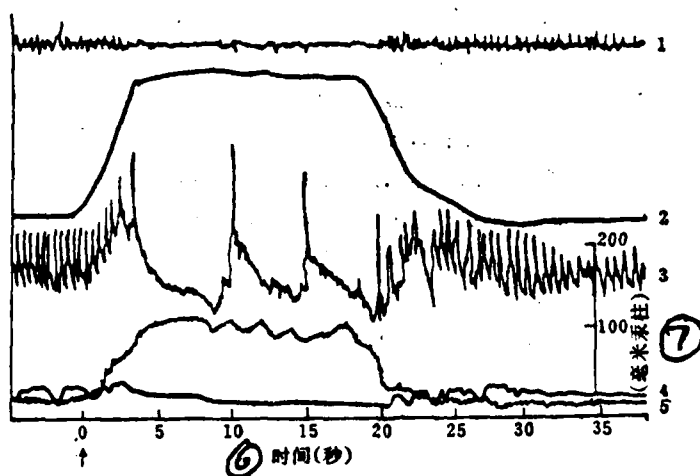


Chart 2-9 Respiratory and Circulation Changes of an Anesthetized Dog Under Negative Overweightness (-5 G)

1. Electrocardiogram
2. G value
3. Arterial pressure
4. Venous pressure
5. Respiration rate indicates overweightness begins

6. Time (seconds
7. Millimeters on mercury column

Some people think that the obstruction of consciousness caused by foot + head overweightness is not necessarily due to hyperemia in the brain area but is partially due to the mechanism of analogous carotid sinus syndrome. The facts listed in chart 2-6 show that the excessively high blood pressure of the carotid artery formed a strong stimulation of the inner pressure receptor which reflexively caused the heart pulse to suddenly stop and then the blood pressure dropped to a very low level. At this moment, cerebral anemia and fainting are possible and the length of heart palpitations determine the length of fainting. In this way, negative overweight action time cannot be very long for when it is very long it is difficult to endure.

#### 4. Respiratory Reactions

Respiration difficulty is mainly created by shifts of the diaphragm and pressure on the lung area. At the same time,, one of the reasons for respiration difficulty is the abundance of blood in lung circulation. Under 3 G negative overweightness, the respiration rate rises slightly (the increase is under 3-4 times/minute) owing to the compensation function of the human body, moisture volume drops 120-150 milliliters and lung activity decreases (lowers about 1,000 milliliters). Yet, under 3 G negative overweightness, the respiration rate drops. Very high negative overweightness can also cause respiration to stop completely. Arterial blood oxygen saturation is also decreased by

the impairment of respiration.

#### 5. Upward Shifts of Organs and Tissues

Negative overweightness causes suspended organs and tissues to shift upwards. Diaphragm upward shifts force the heart and lung outlines to shrink. Upward shifts of the eyeballs cause the feeling that the eyeballs are protruding out of the eye sockets and that the eyelids are difficult to move. Upward shifts of the limbs causes difficulty in muscle movement.

### III. Physiological Reactions of Horizontal Overweightness

In horizontal overweightness, whether it is back → chest or chest → back, the physiological reactions caused by body fluid weight increases are generally lighter than in positive and negative overweightness. This is especially true in blood kinetics because the great majority of large blood vessels in the body are distributed along the long axis of the body and thus their blood flow is effected little by horizontal overweightness. Body fluid forward and backward (chest → back or back → chest) shifts are limited to smaller blood vessels and therefore do not seriously influence the supply of blood to the head. The internal organ shifts created by horizontal overweightness are naturally in the forward and backward directions and they are less serious than those in negative overweightness. Below we will describe the main actions of horizontal overweightness.

#### 1. Influence on Respiration

When horizontal overweightness is below 6 G, besides feelings



of specific pressure maintained in weight areas, there are generally no other feelings. Sometimes there are feelings of specific pressure in the back area and sometimes there are feelings that the chest and rib bones are pressing the lung area, yet they are relatively weak. This is because pressure distribution is relatively even and the bearing area is wide and therefore is not easily detected.

Starting from 6-8G pressing on the chest-abdomenal area becomes gradually more noticeable, respiration difficulty gradually increases and chest stuffiness and pain sometimes occurs. It can be seen from an X ray that compression of the lungs presses on the ribs and spine in the back. If the direction of overweightness is from the back to the chest, besides lying in a reclining position, pressure will be lighter because the breast bone can shift outwards from the pressure. Mechanical pressure on the lung tissues will cause a series of respiratory abnormalities. When pressure acts in an appropriately maintained area such as the back resting on a chair or bed, there are no uncomfortable feelings. On the contrary, although pressure from the back to the chest is relatively light, it is easy to feel uncomfortable. X ray fluoroscopy shows that under chest → back overweightness, upward diaphragm shifts are caused by pressure on the lung cavity and this is also one reason for respiration difficulty.

Respiration difficulty and chest pains are one limiting factor of endurance to horizontal overweightness. The starting

point of respiration difficulty follows the different directions of overweightness. Those from the back to chest occur earlier because the chest and backbone can move and the abdomen has no bone covering. At the same time, it is also necessary to sustain the weight of the spinal column and pelvis and safeguard single flexible ribs as their sustaining ability is weak. If the action of overweightness is from the chest to the back, pressure is on the spinal column and the internal organs in the chest-abdominal cavity press towards the back. Because the back has the support of a chair or bed, support is relatively strong and thus respiration difficulty and chest pains are relatively mild. Generally speaking, the respiration difficulties caused by horizontal overweightness occur at over 8 G.

Under horizontal overweightness, very large variability and diversity appear in respiration recordings. It not only follows the size and variation of the G number but also has differences according to the individual's reactions. Although the majority of people begin to show exhaled carbon dioxide lung volume, lung activity, moisture content and pulmonary alveolus decreases when chest → back overweightness is over 4 G, respiration rate and exhaled oxygen content rise. Beginning from 5 G, respiratory changes are more noticeable. They appear in respiration rate increases and moisture and the highest respiration volume decreases. For example, when chest → back overweightness is over 5 G, the highest respiration volume drops to 60% of normal and when overweightness is even higher, this

causes respiration irregularities and suffocation. Sometimes inhalation stops midway which results in rapid respiration. Aside from this, many other respiratory irregularities occur. In spite of this, under 12 G, voluntary respiration is not obstructed. Proceeding from this point, it can be said that endurance to horizontal overweightness is relatively high. Tables 2-2, 2-3 and 2-4 outline the tendencies of respiratory changes under horizontal overweightness.

① 项 目	② 对 照 值	5G	8G	10G	12G
④ 呼吸率(次/分)	13~14	22	30	—	39
⑤ 潮气容积(毫升)	491~590	491	411	—	318
⑤ 每分钟呼吸容积(升/分)	8~8.5	11	12	—	13
⑥ 氮气排出(升/30秒)	1.3~1.6	1.6	1.5	—	1.4
⑦ 氧耗量(毫升/分)	274~306	333	478	584	—
⑧ 肺活量					

Table 2-2 Respiratory Reactions of Chest → Back Overweightness

1. Item
2. Comparative value
3. Respiration rate (times/minute)
4. Moisture volume (milliliters)
5. Respiration volume per minute (liters/minute)
6. Nitrogen discharge (liters/30 seconds)
7. Oxygen consumption (milliliters/minute)
8. Pulmonary activity

	① 对 照	5 G	② 对 照	8 G	③ 对 照	12 G
④ 呼吸率(次/分)	13.8 ± 4.0	22.2 ± 6.4	13.4 ± 4.2	29.6 ± 14.2	14.4 ± 4.4	39.2 ± 9.2
⑤ 潮气容积(毫升)	580 ± 125	491 ± 179	635 ± 204	411 ± 140	590 ± 243	318 ± 208
⑤ 每分钟呼吸容积(升/分)	8.0 ± 1.2	10.9 ± 2.6	8.5 ± 2.6	12.2 ± 2.0	8.6 ± 1.8	12.5 ± 5.6

Table 2-3 (Key, next page)

Table 2-3 The Effects of Chest → Back Overweightness on Respiration Rate, Moisture Volume and Respiration Volume Per Minute

1. Comparison
2. Comparison
3. Comparison
4. Respiration rate (times/minute)
5. Moisture volume (milliliters)
6. Respiration volume per minute (liters/minute)



① 超量方向 ↓	1 G	4 G	6 G	8 G
A 	4.1 ± 0.45	2.78 ± 0.67	1.48 ± 0.67	—
B  12°	4.3 ± 0.41	3.37 ± 0.52	2.26 ± 0.70	1.50 ± 0.46

Table 2-4 The Effects of Chest → Back Overweightness on Pulmonary Activity

1. Overweight Direction

Following the shrinking of moisture volume, there is pulmonary extravasated blood and lack of blood in the pulmonary lobe and cardiac output decreases. Blood oxygen saturation began to decrease 13% after one-half minute at 6 G and at 8 G it decreased 23 -25%.

Another effect of horizontal overweightness on the lungs is the uneven distribution of blood in the lungs. Chest → back overweightness causes blood to collect in the back side of the lungs and back → chest overweightness causes it to collect in the front side of the lungs. Because of this, there is created partial pulmonary alveolus deficiency of blood and partial pulmonary alveolus hyperemia. This influenced the gas exchange between the pulmonary alveolus and blood and caused a decrease in arterial blood oxygen

saturation.

The adoption of a suitable posture can decrease respiration difficulty caused by chest → back overweightness and perhaps produce respiration symptoms under higher overweightness. For example, when the body is inclined forward 25°, there is a withdrawal of 2 G of moisture volume as compared to when in a positive seated position. At the same time, there is improvement in other respiratory targets.

Back → chest overweightness and chest → back overweightness are dissimilar, that is, the internal organs press forward and not back. Because of this, chest and abdominal pains occur. These pains often become a restricting factor in endurance to back → chest overweightness. When the chest-abdominal area is firmly bound, the above mentioned situation can be improved and endurance can then correspond to chest → back overweightness. The mechanical pressure sustained by the chest area under back → chest overweightness is smaller than under chest → back overweightness and therefore respiration obstruction is relatively small. When back → chest overweightness is under 8 G, this generally produces serious respiration difficulty.

## 2. Influence on the Cardiac Blood Vessel System

Horizontal overweightness causes pressure on the chest and the heart undergoes position shifts and changes in shape. The outline of the heart shrinks, the heart's front outline is level and the heart shifts towards the back. The large veins in the

thoracic cavity and the left and right atria receive the most pressure because the pressure on the inside of the thin walls is small and the pressure there is the easiest to subside. When chest → back overweightness is over 12 G, this area's circulation system blood flow stops, thus causing a decrease of filling in the right side of the heart, a great decrease of blood supply to the lungs and even causes a severe lack of blood saturation. Fortunately, the surrounding of the pulmonary artery and right atrium have soft tissue or body fluid so that aside from when the overweight value is very large, they are generally unlikely to be pressed to complete blockage. However, its influence cannot be overlooked. Chart 2-10 shows the changes of an electrocardiogram, the volume of the left side of the heart and the pressure in the left ventricle. If a curve of the relationship of volume and pressure is drawn, it can be seen that the pressure drop cannot cause the volume to produce a corresponding increase. This is because at this time there is a decrease of blood in the pulmonary vein entering the heart. Only if the volume increases to a specific level can there be an increase in pressure and yet when the pressure increase is slow it does not increase in proportion to the volume. This is because the amount of work of each heart beat has decreased. The changes of the electrocardiogram recorded in chart 2-10 have still not yet appeared. Yet, at over 12 G, we often see extra systole, T wave inversion, atrium weakening and serious sinusal rhythm irregularity.

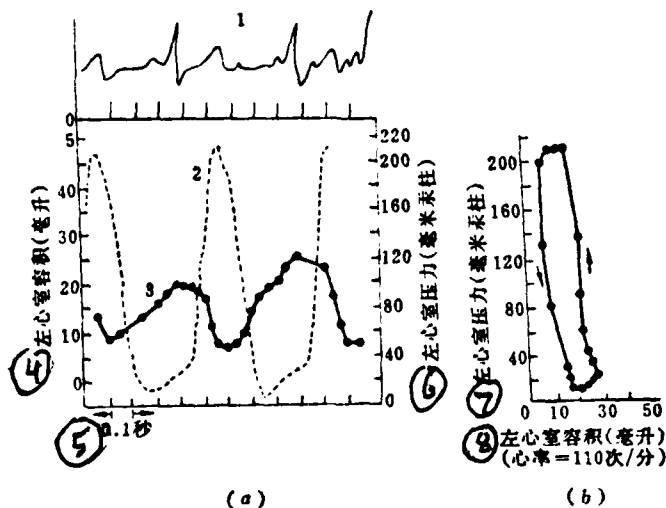


Chart 2-10 Cardiac Blood Vessel Kinetic Data on a Typical Case (Anesthetized Dog) of the Effect of Horizontal Overweightness

a. Relation of left ventricle volume and its pressure: when there is overweightness, the left ventricle volume greatly decreases and the amount of work per pulse (the volume-pressure circle area can be taken as representative) also decreases and thus pressure also continues to decrease. This shows that when pressure is put on the heart, it becomes harder and easily expands.

1. Electrocardiogram
2. Ventricular pressure
3. Heart volume

b. Relation of left ventricular pressure and its volume

4. Left ventricular volume (milliliters)
5. 0.1 seconds
6. Left ventricular pressure (millimeters on mercury column)
7. Left ventricular pressure (millimeters on mercury column)
8. Left ventricular volume (milliliters). (Heart rate=110 times/minute)

If horizontal overweightness is not very large and exposure

time is not very long, then the heart rate generally rises. For example, at normal gravity, the heart rate averages 75 times/minute, when chest → back overweightness is 6 G the heart rate speeds up to 140-150 times/minute and at 8-12 G it can increase to 180-190 times/minute. If the overweight value is even greater, then the heart rate lowers and when the overweight value is over 15 G the heart rate can become very slow and the accompanying rhythm is lost. If overweight time is excessively long, the heart rate also drops and after 15-20 seconds of exposure to chest → back overweightness of 12 G, the heart rate can decrease 50%. If there is only 2 G chest → back overweightness and if exposure time is excessively long, this can also cause the heart rate to lower.

Blood pressure rises under horizontal overweightness and its developmental trend is similar to that of positive overweightness. However, it only occurs when the overweight value is relatively large. Under horizontal overweightness, peripheral blood vessel resistance hyperfunction can also be observed. When chest → back overweightness is 4-5 G, peripheral blood vessel resistance increases 29-38% and after overweightness ends, peripheral blood vessel resistance is 37% higher than normal. One of the mechanisms of human body compensation for horizontal overweightness is continuous storing up of blood in the pulmonary artery which is shown in pulmonary movement, rises in venous blood pressure and the unbalanced systole volume in the left and right ventricles. An increase in overweightness causes blood



pressure in the right atrium to increase and 5 G overweightness can cause a threefold increase in its pressure.

Under horizontal overweightness, blood pressure changes in the whole body are relatively small. This is because blood pressures changes are determined by the level height of the distantly separated heart. If lying on the back, lying on the stomach or lying on the side postures are adopted, although the head is above the level of the heart, the difference in height is very small and therefore the liquid static changes are not large and the effect on blood pressure is also relatively small. Further, for the influences of horizontal overweightness on blood kinetics, besides the already mentioned pressed cavity veins and atrium, the others are not worth mentioning. This is because the influence of horizontal overweightness on side vessel fluid static pressure is not great. Therefore, if the overweight value reaches 12 G, vision obstruction is very rarely observed.

### 3. Effects on Digestive and Excretory Functions

Horizontal overweightness has a specific effect on the secretion of gastric juices. After 30 seconds exposure to 3-5 G overweightness, the secretion of gastric juices is seriously restricted. This can last for 10-30 minutes and later change to become an excitation stage wherein there is a drastic three to five fold increase in secretion. When the chest → back overweight value reaches the limit of endurance, overweightness is excessively strong and the restricting effect of the secretion of gastric juices can continue for as long as three days. Acidity rises and

enzyme activity decreases. At the same time, certain digestive enzyme protein synthesis functions are also inhibited.

Horizontal overweightness can also cause the appearance of red and white blood cells and a small amount of protein in the urine. The urine discharge rate increases and there is a large increase in the amount of potassium and chlorine discharged. Under greater overweightness, liver cells show adipose infiltration. This type of effect can last 2-30 days after overweightness has stopped.

#### 4. Crush Injuries of Places on the Body That Are Pressurized

When the horizontal overweight value is very great, the growth rate very fast and action time relatively long, there is a lack of flexibility on the back as well as a deficient binding and support system, then it is possible for the body to sustain injury from pressure. Centrifugal machine experiments showed that under chest → back overweightness, the pressure of the area on the back receiving pressure increased, sometimes back pains and purple spots appeared, chest-abdominal muscle activity strengthened, amplitude increased and upper and lower limb bending and pressured areas sometimes produced pain. Limb crushing injuries and pain is often one of the factors limiting endurance to horizontal overweightness. Yet, after using suitable protective measures such as binding straps, soft cushions and support systems, it can be lightened or avoided.

#### 5. Electroencephalogram Changes

The basis tendency is similar to positive overweightness but

it appears at a higher overweight level. For the general situation, see the previous section on the electroencephalogram of positive overweightness. Below we will further discuss the special characteristics of related central electric activity changes under the skin. Horizontal overweightness of 3-5 G causes the electric activity of a cat's brain reticular structure to have specific phase changes. The first phase is frequency rise, the second phase is the transition phase and the third phase is the stationary phase. Under horizontal overweightness, electric activity changes of the reticular structure and lower thalamus often appear prior to cerebral cortex electrogram changes. Because of this, some people infer that this is because the reticular structure, mesencephalon and lower thalamus are more sensitive to lack of oxygen and therefore are effected by functional changes even earlier than the cerebral cortex. This explanation seems to be upheld in view of the corresponding relationship of carotid artery pressure decrease and electroencephalographic changes. However, some research data has confirmed that during the initial period of horizontal overweightness, before blood kinetic changes have appeared, there were changes in the electric activity of the reticular structure. We can see that it is not necessarily related to blood circulation changes.

#### 6. Presenting Symptoms

When horizontal overweightness is under 6 G, generally, aside from feelings of pressure, there are very rarely any other unhealthy

feelings. Uncomfortable symptoms begin to occur from 6-8 G on and the most common are cerebral pains, abdominal pains, muscle pains, eyelid pains and the flow of tears. Very high horizontal overweightness can also cause respiration difficulty and heart rate imbalance. When over 12 G, it can bring on vision defects and loss of consciousness which is very dangerous. If we consider that it is possible to encounter this type of high horizontal overweightness, then we must give attention to stronger protective measures.

#### IV Physiological Reactions to Lateral Overweightness

The increases in body fluid weight and the physiological changes produced from this which are brought about by lateral overweightness have no differences in the left and right directions and its effects are smaller than that of positive overweightness. The physiological reactions to lateral overweightness are more or less similar to those of horizontal overweightness, but the directions are different. To avoid repetition, we will only give a brief account of the special characteristics of lateral overweightness.

##### 1. Organ Shifts

When lateral overweightness is greater than 6-7 G, the heart and lungs shift laterally causing left and right imbalance of the diaphragm and clockwise or counter clockwise turning of the heart. On one side there is compression and on the other side there is dilation and on the dilated side there is a

deficiency of blood. All of these actions seriously effect the functions of the lungs and heart, especially the heart. Sometimes pains are felt in the brain and there is the uncomfortable feeling of trachial pulling as well as respiration difficulty.

## 2. Pressure and Tissues

Lateral overweightness can cause stomach intestinal tract and abdominal organ pressure towards one side. Only because the abdominal walls relax does there exist a large amount of gas that can flow within the internal organs and this, aside from when overweightness is very large, is very critical; or when action time is excessively long there are usually no apparent unendurable and uncomfortable feelings. On the contrary, sometimes violent and continuous lateral overweightness can cause abdominal pains and the left and right sides to suffer pressure pains.

## 3. Blood Gathering on One Side of the Body

Because lateral blood vessels are relatively tiny, blood flow is slow and aside from when overweight time is very long, it generally does bring about serious symptoms.

Generally speaking, the physiological effects of lateral overweightness are mainly in heart and lung shifts which greatly influence the human body. In other physiological reactions, aside from when overweightness is very large, there is drastic growth and when action time is excessively long, they are generally not sufficient to cause people discomfort. Although this being the case, heart and lung lateral shifts easily bring about

serious after effects and therefore create a limiting factor for people's endurance to lateral overweightness. Lateral overweightness can generally not compare with horizontal overweightness when in a suitable posture.

### Section Three The Effects of Overweightness on Flight Capabilities

The effects of overweightness on flight capabilities is, in practice, a very worthwhile problem to examine, especially because sometimes prior to the serious physiological reactions brought on by overweightness, flight and fighting capacities have already been weakened. This occurs in aviation and space navigation and therefore we must fully consider the effects of overweightness on flight capabilities.

The effects of overweightness on flight capabilities mainly appear in the failing of visible space direction and operating capabilities and especially in the effects on visual capabilities. This is because sense of vision is a sense passage that occupies a controlling position for the pilot. Under negative overweightness effects, vision obstruction also occupies an important place. The unfavorable effect of overweightness on space directional capabilities lies in its causing errors in vision and mistakes in control. The effects of overweightness on limb activity is centered on the acute increase of limb weight which causes people to feel heavy and their activities to be difficult. In this way, control movements necessarily suffer unfavorable effects. Tremendous overweightness can cause limb heaviness to reach a level of

basic immovability. Yet, the effect on limb movement capabilities when there is a non-parallel overweight direction is relatively small.

When overweightness reaches a specific level, the functions of the central nervous system can also be damaged which is shown in non-clarity of consciousness. When serious, there can also be loss of consciousness. However, this situation cannot be allowed to appear and is an unshirkable responsibility to be guaranteed in engineering and medicine. This section focuses on introducing the effects of overweightness on sense of vision, space direction and control capabilities. It does not stress the effects of overweightness on consciousness, thinking etc.

#### I. The Effects of Overweightness on Consciousness

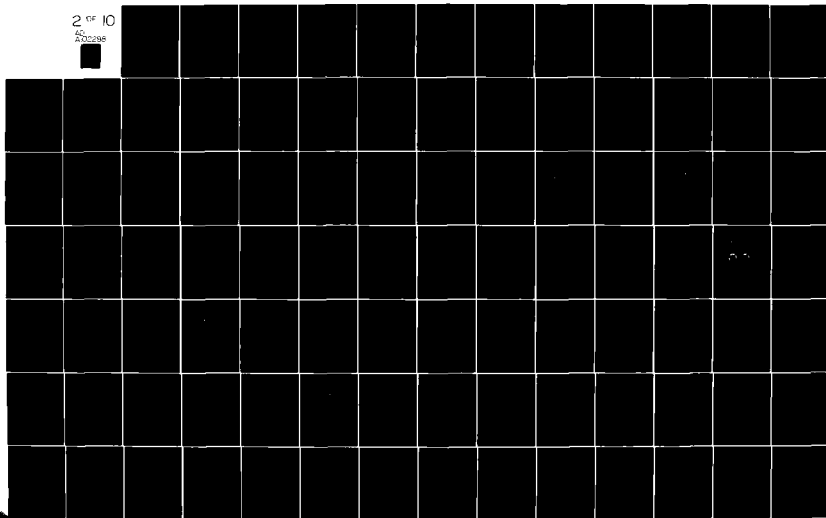
Consciousness is the reflection of things in the outside world on the brain. It originates in the peripheral receptors, undergoes nerve signal transmission and finally is the outcome of going through high level nerve centers. Accordingly, because the emitted signal receptor is obstructed by overweightness, consciousness is effected, the central analyser is injured (for example, lack of oxygen, deficiency of blood, vibrations, strong stimulations etc.) and it can also disturb consciousness and space directional capabilities. At the same time, it can also cause many defects in controlling movements. This chain of physiological changes can, on the one hand, no doubt excite an increase in limb weight. On the other hand, we cannot overlook

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the direct effect of overweightness on the high level center movement control area. To control the above mentioned physiological change links, below we will cite numerous facts which are not difficult to explain.

Among the various effects of overweightness on consciousness, sense of vision is the most outstanding. Sense of vision is essential for flight operation and therefore we will give a more detailed account below of the major abnormalities causes in the area of sense of vision.

#### 1. General Vision Obstruction

Positive and negative overweightness can both cause vision obstruction. If horizontal overweightness does not have the mixed component of positive overweightness, then it will probably not cause vision obstruction. Thus, when overweightness causes the nerve center to become seriously obstructed, it will naturally also be accompanied by vision failure (see tables 2-5 and 2-6).

① 视觉和意识障碍	② 平均超重值(G)	③ 标准差(G)	④ 全距(G)
⑤ 灰 视	4.1	0.7	2.2~7.1
⑥ 黑 视	4.7	0.8	2.7~7.8
⑦ 失 意识	5.4	0.9	3.0~8.4

Table 2-5 Numerical Values of Vision Obstruction Caused by Positive Overweightness (1,000 testees, overweight growth rate was 1 G/second)

1. Vision and consciousness obstruction
2. Average overweight value (G)
3. Standard deviation (G)
4. Total distance (G)
5. Grey vision
6. Blackened vision
7. Loss of consciousness

① 视觉障碍		② 负超重值 (G)				
		1	2	3	4	5
③ 无防护	⑤ 眼结合膜渗血	0	0	40%	—	—
	⑥ 视觉能力下降	0	0	40%	—	—
④ 用加压面罩防护	⑦ 视觉能力下降	0	0	10%	20%	30%
	⑧ 眼结合膜渗血	0	0	0	0	0

Table 2-6 Occurrence Rate of Vision Obstruction Under Negative Overweightness (exposure time - 10 seconds)

1. Vision obstruction
2. Negative overweight value (G)
3. Without protection
4. Used pressure face guard protection
5. Eye conjunctiva oozes blood
6. Vision capabilities decrease
7. Vision capabilities decrease
8. Eye conjunctiva oozes blood

Note: in the table, the numerical values are the occurrence rates.

## 2. Visual Threshold

Positive overweightness causes the visual brightness threshold (the seen brightness value) to radically rise (becomes poor). Yet, if a person is wearing anti-load clothing (which is anti-overweight clothing) for protection, then this type of effect weakens. The numerical values of the effects of positive overweightness on the visual brightness threshold can be seen in chart 2-11. The effect of horizontal overweightness is much

smaller than that of positive overweightness.

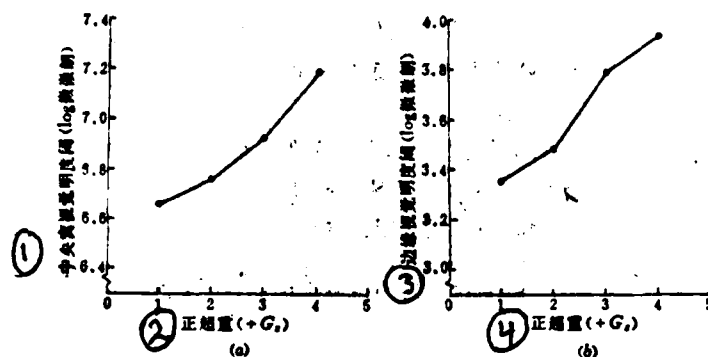


Chart 2-11 The Effect of Positive Overweightness on the Visual Brightness Threshold

- a. Central pit vision
- b. Peripheral vision

- 1. Central pit visual brightness threshold (log picolight)
- 2. Positive overweightness (+ G<sub>2</sub>)
- 3. Peripheral vision brightness<sup>2</sup> threshold (log picolight)
- 4. Positive overweightness (+ G<sub>2</sub>)

Positive overweightness causes the visual luminosity ratio threshold (the perceiving brightness deviation) to rise (become poor). Only in situations in which stimulant strength is weaker does horizontal overweightness have an effect on the luminosity discrimination threshold (see chart 2-12).

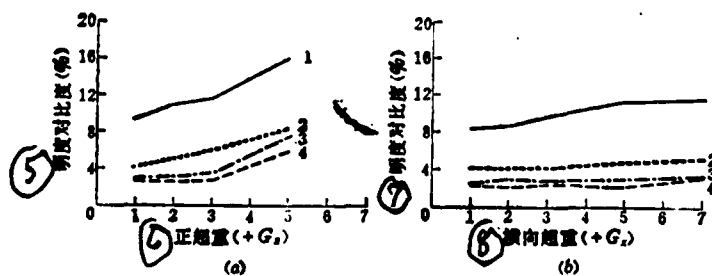


Chart 2-12 (Key, next page)

Chart 2-12    The Effect of Overweightness on the Visual Brightness Discrimination Threshold

- a. Central pit vision
- b. Peripheral vision
- 1. Background brightness 0.03 feet · light
- 2. Background brightness 0.29 feet · light
- 3. Background brightness 2.9 feet · light
- 4. Background brightness 31.2 feet · light
- 5. Brightness ratio (%)
- 6. Positive overweightness (+  $G_z$ )
- 7. Brightness ratio (%)
- 8. Horizontal overweightness (+  $G_x$ )

3. Vision Sensitivity and Visual Power

When positive overweightness increases, visual power (visual dissociation power) becomes poor yet the effect of horizontal overweightness is much smaller than that of positive overweightness and when target brightness is relatively high, the effect is smaller. When horizontal overweightness is over 8 G, sometimes blurry vision is created from the accumulation of tears and cornea deformation.

4. Range of Vision

Positive overweightness causes range of vision to shrink. The general pattern of shrinkage begins with a loss of brightness in peripheral vision and finally prior to approaching blackened vision there is only a small  $5^\circ - 10^\circ$  range of vision in which things can be seen. If there is protection on the outside of the eyes, when horizontal overweightness is over 4 G, blurry vision and range of vision shrinkage can be caused by the accumulation of tears and focusing difficulties. However, the use of suitable protection can

guarantee peripheral and central range of vision when chest + back overweightness reaches 12-14 G.

#### 5. Instrument Reading

When positive overweightness is under 3 G, the effect is generally not very great. When it is over 3-4 G, the effect is noticeable which causes reading to be slow and mistakes to increase.

#### 6. The Effect of Overweightness on the Electrograms of the Pupils, Regulation, Eye Movement and the Retina

Positive overweightness causes the pupils to enlarge and after blackened vision occurs, the pupils enlarge to their extreme degree. Negative overweightness can cause eye regulation capabilities to decline. When positive overweightness nears grey vision, voluntary eyeball movement is lost. Positive overweightness over 6 G causes the eyelids to droop and it is not easy to open them. Yet, prior to the occurrence of grey vision, color discrimination is not explicitly effected.

#### 7. Hearing

When overweightness causes vision loss, the ability to hear can generally be maintained. In the initial period of loss of consciousness there is sometimes a hearing reflex reaction, but under higher overweightness hearing reaction time can be extended.

#### 8. Consciousness of Time

It is estimated that positive overweightness of 3-4 G will cause the stimulant action time of a person to lower and at 6-8 G it will become higher. On the contrary, when exposure time under 23-25 G chest + back overweightness is short there is no damage

suffered. The error of this type of assessment is possibly the result of lack of oxygen to the brain. There are many other examples of errors in assessment and discernment as well as slow reactions similar to those mentioned above.

## II The Effect of Overweightness on Flight Operation Capabilities

### 1. Hand Position Movement

During the initial period of overweightness, hand position is not precise enough. For example, when the hand is extended quickly upwards from a specific distance errors in using a finger to press a button increase. When there is positive overweightness, the finger position tends toward the bottom or top of the target.

### 2. Operating Power

It goes without saying that under overweightness, limb and operation weight is double or several times greater than normal and to carry out the same operation it is necessary to expend a corresponding amount of increased strength. Thus, the tenseness of related muscles increases and before long there is the feeling of exhaustion. When the movement is in the opposite direction of the overweightness, the increase in the use of power by related muscles is very evident. When the movement is parallel to the direction of the overweightness, there is relatively little increase in the use of muscle power. For example, when there is positive overweightness, lifting of the hand requires the use of a great amount of power but not much power is needed for movements to the left and right. Overweightness not only causes the use of

power in manipulations to increase, but also causes accuracy decline because of irregularities in the use of power for operations.

### 3. Movements to Escape Danger

The first step for a pilot ejecting to escape danger is to pull the screen below so as to start the ejection equipment. It was practically shown that when anti-load clothes were worn to sustain 5-7 G positive overweightness, 16% of the pilots were unable to complete this first step and at 7-8 G, the great majority of pilots were unable to complete this task. However, if at the time an individual's subjective activity can be aroused and a suitable extended hand position adopted, then, even if overweightness is greater, they will still be able to complete the operating task. Because of this, it is necessary to strengthen political and ideological education and carry out appropriate ejection training for the pilots. This will guarantee the necessary safe escape from danger.

When escaping danger in transport aircraft and bombers, it is sometimes necessary for passengers to put parachutes on themselves, walk towards the cabin door and jump out. Under positive overweightness, the average time for putting on a parachute is 17 seconds, yet when positive overweightness is 2 G it is extended to 41 seconds, at 3 G it is extended to 75 seconds and when over 4 G, most people find it difficult to put on a parachute. In reality, very rarely does overweightness reach 4 G in transport aircraft. Overweightness can sometimes reach 4 G in

bombers and therefore it is best that passengers put on parachutes beforehand and carry out serious technical training.

#### 4. Operating Switches and Knobs

Positive overweightness of 5 G causes an increase of 15% in the time needed to operate buttons and knobs. If the hand is relatively distant from the buttons, then this type of movement is very difficult. The power for the hand operation of knobs and levers is closely related to the direction of overweightness. When the hand movement plane is parallel to the direction of overweightness, for example, when there is positive or negative overweightness, the upward and downward movements of the hands are very difficult and operation errors are greater. On the contrary, if movement and overweight direction is perpendicular, for example, when there is positive and negative overweightness, forward, backward, left and right directional movements are less difficult. When utilizing a body form couch or anti-load clothing, even if chest + back overweightness reaches 20 G, the wrist joint can still move up and down and to the left and right. On the contrary, if the elbow joint is used for forward and backward operations, then even if the range of movement is relatively small there is still great difficulty and even total inability. It can be seen from this that in operation design large range moves should, as far as possible, be avoided that are parallel with the overweight direction. Moreover, operations should be carried out with the wrist joint or ankle joint as much as possible and move-



ments using joints above the elbow or knee should be avoided.

#### 5. Pilot Control

Generally speaking, the effect of positive and negative overweightness on flight operation is greater than that of horizontal and lateral overweightness. Positive and negative overweightness over 3-4 G can cause unfavorable effects on flight operational activities. When exposure time is over 10 seconds, operation errors increase. On the contrary, when horizontal overweightness is under 8-12 G, the effect on operation efficiency is generally not very great and when it is over 12-14 G, unfavorable effects can be seen. These mainly appear in the occurrence of visual symptoms, operation difficulties and an increase in errors. After there is a good binding strap system protection, at horizontal overweightness of 16 G they can still manage to complete flight tasks but operation efficiency is relatively poor. Practical experience in space navigation has shown that with proper protective measures, when a space ship is taking off and returning, the encountered horizontal overweightness does not obstruct the completion of assigned flight control tasks.

#### 6. Discernment Capabilities

The effect of relatively little overweightness on man's ability to discern is very small. When positive overweightness is over 3 G, it begins to have a bad effect on discernment capabilities. For example, there are different levels of errors in reading speeds, distinguishing images, mental arithmetics and memory. At 4-5 G, the ability to carry out mental arithmetics notably

declines, at over 6 G the attention span shrinks, at 5-8 G navigation ability becomes poor and at 6-7 G pilots generally cannot calculate the number of spiral circles. However, when overweightness has not yet caused grey vision, its effect on instantaneous recall is still not great. When overweight value approaches its limit, if grey vision, blackened vision and loss of consciousness are produced or when acute abdominal and cerebral pains occur, then the decline of discernment capabilities is more severe. If overweightness has not yet brought on loss of consciousness and it has not lasted for very long, then after overweightness disappears, normal intellectual activity is immediately restored.

#### Section Four Endurance to Overweightness

##### I. Positive Overweightness Endurance

Endurance to overweightness is related to overweight direction, growth rate, action time and the many factors of an individual's condition. Action direction is one of the essential factors among these. Therefore, when writing about endurance to overweightness, it is necessary to first distinguish the action directions of overweightness. Aerospace medicine often takes positive overweightness as the standard of endurance to overweightness and here we will also begin with endurance to positive overweightness.

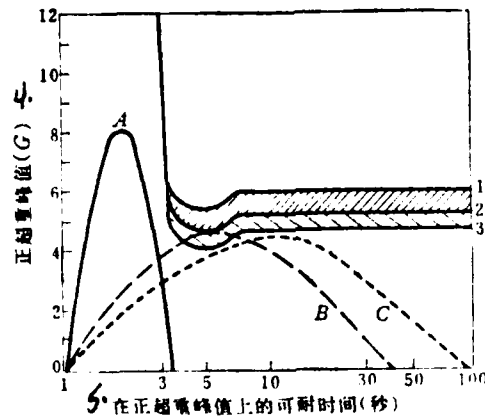


Fig. 2-13 Endurance Time When Positive Overweightness is at Peak Value

Upper right curve lines 1, 2 and 3 separately use loss of consciousness, blackened vision and grey vision as the critical index of endurance; left and lower curve lines A, B and C separately indicate the use of the different growth rates of 7 G/second, 1 G/second and 4 G/second, for the endurance peak value when exposed to overweightness.

4. Positive overweightness peak value (G)

5. Endurance time (seconds) when positive overweightness is at peak value

Based on different actual requirements, people establish many different critical indices for the endurance limit to overweightness. According to the differences of the critical indices, the overweight critical indices also possess differences. Among the commonly used critical indices, there are the grey vision threshold, blackened vision threshold, loss of consciousness threshold and major endurance. Chart 2-13 shows endurance to overweightness and chart 2-14 shows the relation of overweightness rate and endurance to positive overweightness.

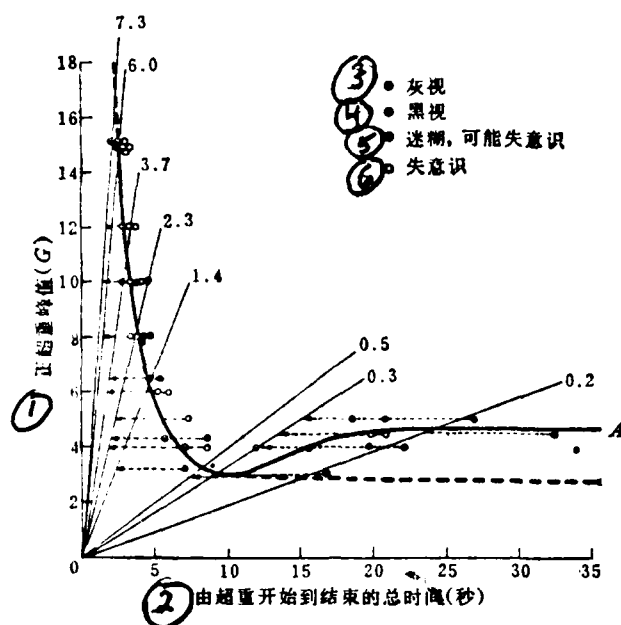


Chart 2-14 Endurance to Positive Overweightness at Different Overweight Growth Rates

1. Positive overweight peak value (G)
2. Total time of overweightness from beginning to end (seconds)
3. Grey vision
4. Blackened vision
5. Blurriness with possibility of loss of consciousness
6. Loss of consciousness

The oblique line shows the overweight growth rate (G/second); the dots and circles are the possible reactions - see upper right corner of chart; curve A shows a person's endurance to overweightness; the dotted line arrow direction positions show the occurrence of symptoms at overweight peak value.

Based on the results of centrifuge tests on 1,000 people, positive overweightness sustained in a seated posture reached a grey vision threshold value of 4.1 G, blackened vision was at 4.7 G and loss of consciousness was at 5.4 G. If the overweight

value was very great and the growth rate was very high, then loss of consciousness occurred very quickly. In this way, it was not easy to separate grey vision, blackened vision and loss of consciousness. For the times from grey vision to loss of consciousness at different overweight growth rates, see table 2-7.

① 超重增长率(G/秒)	② 最短时间(秒)	③ 平均时间(秒)	④ 超重增长率(G/秒)	⑤ 最短时间(秒)	⑥ 平均时间(秒)
2.5	1.6	2.8	5.0	0.9	1.5
3.0	1.3	2.3	5.5	0.8	1.4
3.5	1.2	2.1	6.0	0.7	1.2
4.0	1.1	1.8	6.5	0.6	1.1
4.5	1.0	1.7	7.0	0.5	1.0

Table 2-7 The Times (Seconds) From Grey Vision to Loss of Consciousness Under Positive Overweightness

1. Overweight growth rate (G/second)
2. Shortest time (seconds)
3. Average time (seconds)
4. Overweight growth rate (G/second)
5. Shortest time (seconds)
6. Average time (seconds)

## II Endurance to Overweightness in Different Postures

For the purpose of comparison we combined the observed data of endurance to overweightness in different postures and different directions into tables 2-8 to 2-12. It can be seen from the tables that a person's endurance to negative overweightness is lowest and at 5 G, generally does not exceed several seconds. The main obstructions are blurry vision, face pains and dizziness which people find difficult to endure. Next is positive overweightness to which people's endurance is also very low. The limiting factors are production of grey vision, blackened vision

and loss of consciousness. If the speed of overweight growth is slow (below 0.1 G/second) and the overweight value is below 3-4 G, then this can be endured for a long time without the occurrence of vision and consciousness obstruction. Naturally, the symptoms of exhaustion, weakness and headaches are difficult for a person to endure for a long time. Chart 2-15 shows four types of endurance to overweightness curves and indicates that endurance to negative overweightness is poorest, next is positive overweightness and the best is endurance to horizontal overweightness.

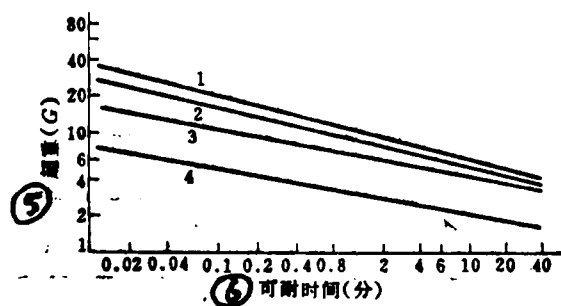


Chart 2-15 Several Types of Endurance to Overweightness

1. Positive overweightness
2. Negative overweightness
3. Chest → back overweightness
4. Back → chest overweightness
5. Overweightness (G)
6. Endurance time (minutes)


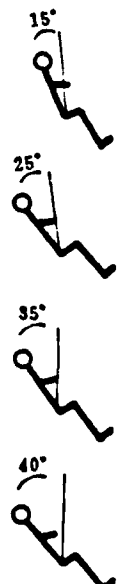
① 姿 势	② 超重方向	③ 耐 力			⑦ 主 要 症 状
		④ 超重值 (G)	⑤ 作用时间	⑥ 超重增长率 (G/秒)	
⑧ (一) 垂直坐姿 	↓	<2.5	⑩ 长 时 间	—	⑫ 可耐受
		3	⑪ 15~25分	0.2~0.5	⑬ 主诉可耐限
		3.5	⑫ 60分	0.07	⑭ 部分人至22分钟不能耐受
		3.5~4	⑬ 15秒	>0.4	⑮ 灰视、黑视
		4~5	⑭ 10~15秒	>0.5	⑯ 主诉可耐限
		6~8	⑮ 5~10秒	>0.5	⑰ 失意识
		9~12	⑯ ~3秒	>0.5	⑱ 失意识
⑨ (二) 后仰坐姿 	↓	4.25	⑳ 5秒	—	㉒ 灰 视
		3.75	㉓ 5秒	—	㉔ 灰 视
		4.00	㉕ 5秒	—	㉖ 灰 视
		4~5	㉗ 5秒	0.1	㉘ 疲劳, 恶心, 苍白, 出汗, 头痛, 背痛, 有时黑视

Table 2-8 A Person's Endurance to Positive Overweightness

1. Posture
2. Overweight directions
3. Endurance
4. Overweight value (G)
5. Action Time
6. Overweight growth rate (G/second)
7. Major symptoms
8. (1) Verticle seated posture
9. (2) Back reclining seated posture
10. Long time
11. 15-25 minutes
12. 60 minutes
13. 15 seconds
14. 10-15 seconds

15. 5-10 seconds
16. 1-3 seconds
17. Endurance
18. Major endurance limit
19. Some people cannot endure this up to 22 minutes
20. Grey vision, blackened vision
21. Major endurance limit
22. Loss of consciousness
23. Loss of consciousness
24. 5 seconds
25. 5 seconds
26. 5 seconds
27. 5 seconds
28. Grey vision
29. Grey vision
30. Grey vision
31. Exhaustion, nausea, paleness, perspiring, headaches, back aches and sometimes blackened vision


① 姿势	② 超重方向	③ 耐力	力	⑦ 主要症状
④ 超重值(G)	⑤ 作用时间(秒)	⑥ 超重增长率(G/秒)		
⑧ 垂直坐姿 	2	100	<0.5	⑨ 主诉可耐限
	3	5~32	0.5	⑩ 主诉可耐限
	4~5	5~6	0.5	⑪ 主诉可耐限
	7.5	~1	-	⑫ 主诉可耐限






Table 2-9 A Person's Endurance to Negative Overweightness (Pilots)

1. Posture
2. Overweightness direction
3. Endurance
4. Overweight value
5. Action time (seconds)
6. Overweight growth rate (G/second)
7. Major symptoms
8. Vertical seated posture
9. Major endurance limit
10. Major Endurance limit
11. Major endurance limit
12. Major endurance limit



[Table 2-10]

Table 2-10. A person's endurance to chest + back overweightness.

① 姿势	② 重量方向	③ 重量值 (G)	④ 作用时间	⑤ 超重增长率 (G/秒)	⑥ 主要症状
⑧ 垂直坐姿		3	⑬ 15~20分	—	③⑩ 主诉可耐限, 呼吸困难, 胸痛
		6~7	⑭ 5分	—	③⑪ 主诉可耐限, 呼吸困难, 胸痛
		15	⑮ 5~10秒	8	③⑫ 主诉可耐限, 呼吸困难, 胸痛
⑨ 直立		5.3	⑯ 13秒	—	③⑬ 胸痛
		5~6	—	—	③⑭ 窒息, 胸痛
		12	—	—	③⑮ 呼吸困难, 胸痛
⑩ 仰卧		6	⑰ >5分	—	③⑯ 可耐限
		8	⑱ 2~5分	—	③⑰ 胸痛, 呼吸困难
		12	⑲ 8~60秒	—	③⑱ 主诉可耐限
		12~15	⑳ >180秒	—	③㉑ 边缘视觉脱失, 黑视, 胸紧 (体形防护)
		25	㉒ 10秒 (包括超重上升和下降时间)	—	③㉒ 在体形防护和束带帮助下减轻胸痛的情况, 不出视黑视, 能完成灯光按钮动作
⑪ 前倾坐姿		28.5	㉓ 几十秒	—	③㉓ 在束带帮助下可耐限
		6	㉔ 11分	—	③㉔ 主诉可耐限
		8	㉕ 3~4分	—	
		12	㉖ 28~30秒	—	
		14~15	㉗ 15~18秒	—	
⑫ 屈曲		6	㉘ 218秒	0.5	③㉘ 小腿剧痛, 呼吸困难
		8	㉙ 60秒	0.5	③㉙ 小腿剧痛, 呼吸困难
		10~12	㉚ 2~14秒	0.5	③㉚ 灰视, 黑视
		—	—	—	—


[Table 2-10 cont'd.]

(46)	姿	(47)	(48)	力	(52)
		重量值 (G)	(50) 作用时间	(51) 重量增长率 (G/秒)	主要症状
	5°	10	—	—	(57) 胸痛
(53)	(五) 15°	14	(56) 1~13秒	0.5	(58) 剧烈胸痛
	伸				
	坐				
	25°	6	—	—	(59) 胸痛
	45°	3.75	5秒	—	(60) 灰视
(54)	(六) 60°	(55) 校正超重大1倍	—	—	(61) 灰视
	抬				
	身				
	85°	6	(62) 30秒	0.55	(64) 可耐受
	卧	7	(63) 30秒	0.55	(65) 呼吸费力, 胸痛
	20°	9~10	—	—	(66) 窒息, 胸痛

1. Posture
2. Overweight direction
3. Endurance
4. Overweight value (G)
5. Action time
6. Overweight growth rate (G/second)
7. Major Symptoms
8. (1) Vertical seated posture
9. (2) Standing erect
10. (3) Lying on the back
11. (4) Leaning forward in seated posture
12. Bent
13. 15-20 minutes
14. 5 minutes
15. 5-10 minutes
16. 13 seconds
17. 7.5 minutes
18. 2-5 minutes
19. 8-60 seconds
20. > 180 seconds
21. 40 seconds (including overweight rise and decreased time)
22. Several tens of seconds
23. 11 minutes
24. 3-4 minutes
25. 28-30 seconds
26. 15-18 seconds
27. 218 seconds
28. 60 seconds
29. 2-14 seconds
30. Major endurance limit, respiration difficulties, chest pains
31. Major endurance limit, respiration difficulties, chest pains
32. Major endurance limit, respiration difficulties, chest pains
33. Chest pains
34. Suffocation, chest pains
35. Respiration difficulties, chest pains
36. Endurable
37. Chest pains, respiration difficulties
38. Major endurance limit
39. Peripheral vision lost, blackened vision, chest tightness (body form couch protection)
40. With a body form couch and binding straps to help lighten chest pains, there is no occurrence of blackened vision and one is able to complete lit button activity
41. Endurable with help of binding straps

42. Major endurance limit
43. Acute pains in shank, respiration difficulties
44. Acute pains in shank, respiration difficulties
45. Grey vision, blackened vision
46. Posture
47. Overweight direction
48. Endurance
49. Overweight value
50. Action time
51. Overweight growth rate
52. Major symptoms
53. (5) Lying back in seated posture
54. (6) Body raised lying on the back
55. Double that of positive overweightness
56. 1-13 seconds
57. Chest pains
58. Severe headaches
59. Chest pains
60. Grey vision
61. Grey Vision
62. 30 seconds
63. 30 seconds
64. Endurable
65. Respiration strenuous
66. Suffocation, chest pains

Table 2-11 A person's endurance to back → chest overweightness.

① 姿势	② 超量方向	③ 耐 力	④ 超量值 (G)	⑤ 作用时间	⑥ 超量增长率 (G/秒)	⑦ 主要症状
(一) 	→		8	⑬ 0.5~1分	—	⑬ 主诉可耐限
			12	⑭ 6秒	—	⑭ 主诉可耐限, 腿痛
			15	⑮ 5秒	—	⑮ 眩晕, 窒息, 血斑
⑧ 直立坐姿 ⑧a (用束带)	→		5	⑯ 118秒	0.5	⑯ 小腿痛, 中度窒息, 疲劳, 头昏
			8	⑰ 41秒	0.5	⑰ 小腿痛, 中度窒息, 疲劳, 头昏
			12	⑱ 4秒	0.5	⑱ 小腿痛, 中度窒息, 疲劳, 头昏
⑧b 伸展	→		5	—	—	⑳ 腹与腓肠肌刺痛
(二) ⑨ 俯伏	↓		12	⑲ 3分	—	㉑ 主诉可耐限
			15	㉒ 5秒	—	
(三) ⑩ 前倾坐姿	→		6	㉓ 11分	—	㉓ 背部、胸部血斑
			10	㉔ 57.8秒	—	㉔ 屏息, 疲乏, 呼吸困难, 少数人失意识
			⑫ 6(个别人)	㉕ 5秒	—	㉕ 失意识
(四) ⑪ 前后卧姿	↓		12	㉖ 1分左右	—	㉖ 主诉可耐限
			10~11	—	—	㉗ 视觉障碍
⑪ 0°~50°	↓		12	㉘ 30秒	—	㉘ 胸痛

1. Posture
2. Overweight direction
3. Endurance
4. Overweight value (G)
5. Action time
6. Overweight growth rate (G/second)
7. Major symptoms
8. (1) Vertical seated position
- 8a. (Using binding straps)
- 8b. Stretched out
9. (2) Lying prostrate
10. (3) Reclining forward in seated posture
11. (4) Front and back lying postures
12. 16 (individuals)
13. 0.5 - 1 minute
14. 6 seconds
15. 5 seconds
16. 118 seconds
17. 41 seconds
18. 4 seconds
19. 3 minutes
20. 5 seconds
21. 11 minutes
22. 57.6 seconds
23. 5 seconds
24. About 1 minute
25. 30 seconds
26. Major endurance limit
27. Major endurance limit, leg pains
28. Dizziness, suffocation, blood spots
29. Shank pains, medium suffocation, exhaustion, dizziness
30. Shank pains, medium suffocation, exhaustion, dizziness
32. Acute pains in thighs, calves and intestinal muscles
33. Major endurance limit
34. Blood spots on back and chest
35. Holding of breath, exhaustion, respiration difficulties and loss of consciousness for a minority of people
36. Loss of consciousness
37. Major endurance limit
38. Defective vision
39. Chest pains


① 姿 势	② 超重方向	③ 耐 力			⑦ 主 要 症 状
		④ 超重值(G)	⑤ 作用时间(秒)	⑥ 超重增长率(G/秒)	
⑧ 立 	→	6	⑨ 30(包括超重上升和下降时间)	—	⑩ 灰 视
	→	7	—	—	⑪ 血管严重充血, 悬垂的前臂和肘部痛, 心脏移位和扭转, 胸痛, 气管受牵偶尔出现
	←	8~10	30	—	⑫ 主诉可耐限, 胸痛, 肘痛

Chart 2-12 A Person's Endurance to Lateral Overweightness

1. Posture
2. Overweight direction
3. Endurance
4. Overweight value (G)
5. Action time (seconds)
6. Overweight growth rate (G/second)
7. Major symptoms
8. Standing erect
9. 30 (including overweight rise and decrease in time)
10. Grey vision
11. Blood vessels seriously fill with blood, hanging forearm and elbow pain, cardiac shifts and turning, chest pains and occasional tracheal pulling
12. Major endurance limit, chest pains, elbow pains

If there is a gradual 40° backward inclination from a positive seated posture, there are no evident changes in endurance to and symptoms of positive overweightness. However, when the backward incline is greater than 40°, endurance gradually increases and only in the 40° - 65° range is the increase not very large. The major limitation of symptoms is grey vision and blackened vision which is shown in chart 2-16. It can be seen from this chart that when the body reclines backwards 20°, the connecting line and overweight action direction of the

retina and aorta only form a  $3^\circ$  included angle; when there is a  $65^\circ$  backward reclining angle it forms a  $50^\circ$  included angle and at  $85^\circ$  it forms a  $75^\circ$  included angle. Therefore, when the body's backward reclining angle is less than  $60^\circ$ , the effect of overweightness on deficiency of blood in the retina is quite large. Only when the body backward inclining angle is over  $65^\circ$  can the retina - aorta line form an angle over  $50^\circ$  with the overweight direction. After this, the restricting symptoms then become excessive in chest pains, irregular heart rhythm and respiration difficulties. These few symptoms are the major factors of endurance to horizontal overweightness. Thus, it can be said that when the body's backward reclining angle is over  $65^\circ$ , endurance to overweightness is mainly controlled by the overweight vector horizontal component and not the positive overweight component. Because a person's endurance to horizontal overweightness is much higher than towards positive overweightness, when the backward reclining angle is over  $65^\circ$ , endurance to overweightness is raised tremendously.

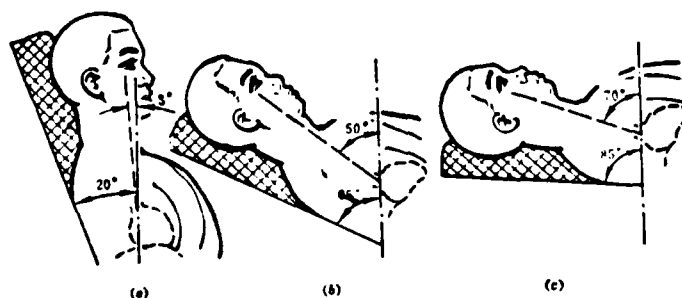


Chart 2-16. The retina-aorta included angle in different seated postures.



- a. Backward reclining angle of  $20^{\circ}$
- b. Backward reclining angle of  $65^{\circ}$
- c. Backward reclining angle of  $85^{\circ}$

The dotted line in the chart indicates the retina - aorta included angle.

When endurance to horizontal overweightness is relatively high but the posture is not good, endurance can also decline. For example, endurance to chest - back overweightness in the standing erect and lying on the back postures is slightly lower than vertically upright seating. There are the following advantages if the legs are bent when in an upright seated position:

(1) the vertical distance between the lower limbs and heart is shortened;

(2) overweightness on the thighs forces the blood to flow back into the heart;

(3) a minute lightening of pressure and tension in the abdominal area which raises the abdominal area's endurance to the pressure of horizontal overweightness.

The best posture for horizontal overweightness is a seated posture in which the body inclines forward to  $12^{\circ}$  and the leg and knee joints are each bent  $100^{\circ}$ . The endurance of the posture can reach a peak value of 16.5 G and a total time of 170 seconds (including overweight increases and decreases in time - see chart 2-17). If the protective measures of a binded strap system, a body form couch and respiration of pure oxygen are used simul-

taneously, the highest endurance can reach to over 26 seconds at 6 G or 1-2 seconds at 29-30 G. The most outstanding points of this posture are that when the body is inclined forward  $12^\circ$ , this can cause pressure on the chest area to lighten, and it can shorten the vertical distance between the head and heart when the legs can extend slightly and in doing so decrease pressure on the shanks, and it can also avoid shank muscle pains. Yet, if the body inclines too much, this is not good. Using an incline of over  $25^\circ$  as an example, endurance decreases close to that of positive overweightness. Chart 2-17 shows that when a good posture is adopted, the body can endure space ship overweightness.

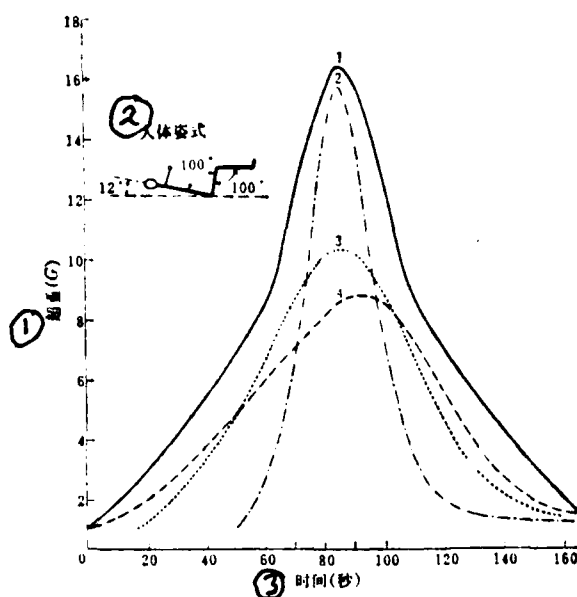


Chart 2-17 (Key, next page)

Chart 2-17 The Endurance of a Person to Overweightness When in a Good Posture

Curve 1 - When a good posture, as shown in the upper left corner of the chart, is used a person can endure overweightness; curve 2, 3 and 4 - the overweightness produced in different space ship rising and return times is used to make a comparison with curve 1.

1. Overweightness (G)
2. Body posture
3. Time (seconds)

The body in a backward inclined posture is not advantageous towards chest → back overweightness because:

(1) backward inclination causes pressure on the chest area to increase;

(2) backward inclination produces symptoms of negative overweightness

Generally, endurance to back → chest overweightness is lower than that of chest → back overweightness. If binding strap protection is used at the same time, then the highest endurance is 5 seconds at 15 G. The main reasons for endurance limitations are:

(1) the chest and abdomen lack support, and respiration is irregular which causes suffocation and exhaustion;

(2) shank pain - If a good binding strap system is used to support the chest - abdominal area and avoids hanging of the shank muscles, then endurance to back → chest overweightness can be equal to that of chest → back overweightness and can even surpass it.

Endurance to lateral overweightness generally does not exceed 10 G and the main obstructions are due to heart and lung shifts and turns which cause functional obstructions to these two organs.

### III Factors Effecting Endurance to Overweightness

Overweightness' strength, action time, growth rate and the effect of its action direction on the human body have been mentioned previously and we will not repeat them. Instead, we will supplement it with the following few points:

#### 1. Accumulated Effects of Overweightness

If many experiments on overweightness are carried out, the interval between each experiment should be several hours to several days. If at the time the overweightness does not cause injury, then afterwards there cannot be the accumulated effects of protracted after effects and overweightness. Some people have reported that during a three year period, 4 male subjects underwent 246-1,198 positive overweightness experiments. Some of the subjects had grey vision 87-248 times, blackened vision 47-299 times and loss of consciousness 3-23 times. The total time of grey vision was 8-22 minutes, the time of blackened vision was altogether 4-30 minutes and the time of loss of consciousness was 0.4-4.9 minutes. The results were that no protracted after effects and accumulated effects were seen. Yet, animal experiments have shown that if the interval between each time of overweightness was very short, say 1-15 minutes, then undeniable accumulated effects were observed. In other words, accumulated effects occurred only when the action interval time was not very long, but when recovery time was not sufficient. then they could appear.

## 2. The Coordinated Action of Overweightness and Environmental Factors

Various factors are often encountered in aviation and space navigation that coordinate with or are supplementary to overweightness. The joint action of these factors, such as high temperature, low temperature, ionization radiation etc. can cause endurance to overweightness to decrease (see table 2-13).

① 条件类别	② 联合条件	③ 超重耐力
	⑫ 气温36.7℃ 相对湿度77%	
	⑬ 气温24~38℃	③② 不变
② 高温	⑭ 气温38~71℃	↓
	⑮ 皮温37℃	↓
③ 低温	⑯ 皮温25℃	↑
	⑰ >3300米高度	↓
④ 缺氧	⑱ >3600米高度	↓
⑤ 过度换气	⑲ 过度换气	↓
⑥ 呼吸气体成分	⑳ 适当增高氧气或二氧化碳	↑
	㉑ 进食后1.5~2小时	↑
	㉒ 大量饮水后	↑
⑦ 饮食和营养	㉓ 注射胰岛素使静脉血糖下降	↓
	㉔ 服用大量葡萄糖	↓
	㉕ 饮酒	③③ 不变
	㉖ 机体缺钠	↓
⑧ 辐射	㉗ 250~850伦辐射后1~9天进行超重	↓
	㉘ 14~120天	↓
⑨ 长期卧床	㉙ 7~60天	↓
⑩ 失重	㉚ 失重飞行几十秒钟之后, 或失重下长时间停留之后	↓

Table 2-13 (Key, next page)

Table 2-13 Coordinated Action of Various Conditions and Overweightness

1. Condition classification
2. High temperature
3. Low temperature
4. Anoxia
5. Excessive breathing
6. Respiration gas component
7. Diet and nutrition
8. Radiation
9. Long period of lying in bed
10. Weightlessness
11. Combined conditions
12. Atmospheric temperature 36°C, relative humidity 77%
13. Atmospheric temperature 24° - 38°C
14. Atmospheric pressure 38° - 71°C
15. Skin temperature 37°C
16. Skin temperature 25°C
17. Altitude greater than 3,300 meters
18. Altitude greater than 3,600 meters
19. Excessive breathing
20. Suitable increase of oxygen or carbon dioxide
21. 1.5-2 hours after food intake
22. After large amount of drink
23. Injection of insulin causes drop in venous blood sugar
24. Intake of a large amount of glucose
25. Drinking of wine
26. Lack of sodium in human body
27. After 250-850 rontgen radiation, overweightness for 1-9 days
28. 14-120 days
29. 7-60 days
30. after weightless flight for several tens of seconds or after long weightlessness stops
31. Endurance to overweightness
32. No change
33. No change

Note: ↑ indicate rise in endurance to overweightness and ↓ indicates decrease in endurance.

### 3. Individual Conditions

When their constitution is strong and more people carry out single and double parallel bar, gyro wheel, double ring and rotational physical training and flight experience, endurance to

overweightness is relatively high. However, exhaustion, insomnia, body weakness and low blood pressure can cause endurance to overweightness to decline. The carrying out of suitably patterned exercises in a centrifuge and aircraft have a specific advantage to raising endurance to overweightness but excesses should be avoided. Generally, an individual's constitution, ideological consciousness and present body and functional state can all effect endurance to overweightness.

#### Section Five Protective Measures Against Overweightness

Protective measures against overweightness can more or less be divided into two major categories. The first category is the adoption of engineering technological means to decrease the overweight numerical value of space ships and aircraft. These are very important protective channels and they are especially important for space ships. However, the sole reliance on engineering measures cannot completely resolve the problems, because sometimes, for reasons of fighting demands, aircraft cannot avoid sustaining high overweightness. To lighten the weight of technical equipment, a space ship cannot decrease the overweight numerical value as low as is hoped. Aside from this, the second category of protective measures are means to raise the human body's endurance to overweightness.

##### 1. Appropriate Postures and Controllers

This was already described in detail previously and here we need only to mention it briefly. The use of a 10° - 12° forward inclined seated posture and 100° bent legs provides highest endurance for chest → back overweightness - 170 seconds at

16.5 G. To resist the unfavorable effects of overweightness, the closer the distance of the hands and feet to the position of the controller the better. Furthermore, it is best for the plane of control activities to be perpendicular to the direction of overweightness and control activities should be separately limited to the use of the ankle, wrist and finger joints.

## 2. Resisting Movements

Muscle tension can raise endurance to overweightness. For example, pressure to the front of the body and tightening of the abdominal muscles can cause the blood to flow back into the heart, can shorten the distance between the eyes and heart and thus raise endurance to overweightness. After experienced pilots undergo training, immediately before approaching overweightness they carry out tense muscle movements. For example, the shank exerts force on the rudder, the thighs tighten the binding straps, the hands and elbows cause the neck and abdominal muscles to tighten and thoracic respiration increases pressure in the chest so that the individual's endurance to overweightness is raised. These measures are especially effective for positive overweightness.

## 3. Anti-Load Clothing, Also Called Anti-Overweight Clothing or Anti-G Clothing

There are many styles but there is one basic principle of design. The air-filled method is used to air-fill a gasbag tightly on the abdomen and the two sides of the shanks and thighs. Also, air tube gasbag pressure on the lower limbs and abdomen area is used to draw tight the elastic band outside the tube to constrict the abdominal and lower limb areas. In this way, the



flow of blood in the large blood vessels to the lower half of the body caused by positive overweightness can be decreased, thus raising endurance to overweightness (1 - 1.2 G). Side tube anti-load clothing can raise endurance to overweightness 1.7 - 2.0 G. There is also a type of anti-load clothing which uses an air-filled sleeve suit around the four limbs and can raise endurance to 2.6 G.

Chart 2-18 is a schematic drawing of five bag and side tube anti-load clothing.

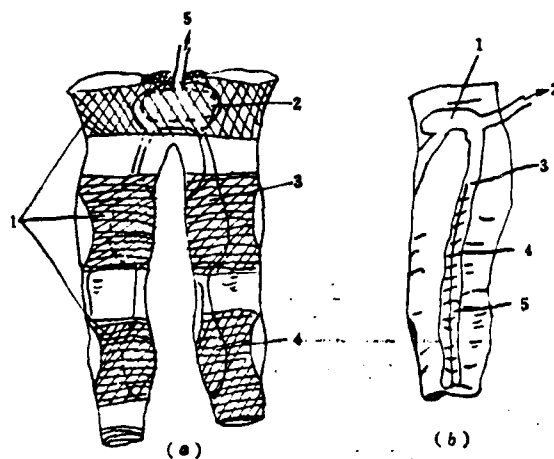


Chart 2-18 Schematic Drawing of the Structures of Two Types of Anti-Load Clothing

- a. Five bag type
- b. Lateral vessel type

Five bag type anti-load clothing is made of five joined bags placed in trousers (1). In the trousers, one bag is for pressure on the abdominal area (2), two bags are separated inside for pressure on the two thighs (3) and two bags are for pressure on the

left and right shanks (4). This rubberized bag opens to a pressure regulator and air compression case (5). When there is overweightness, the pressure regulator opens automatically allowing the bag to fill with air thus pressing on the abdominal area, thighs and shanks. This controls expansion in these areas.

Side tube type anti-load clothing also uses a rubber bag to press on the abdominal area (1). When only expansion of the two legs is being controlled, the system uses the filled air of the side tube (3) on the two sides of the trousers to pull the belt outside the tube tight, thus controlling the expansion of the trousers (5). The source of air and the pressure regulator are the same as that of the five bag style only the pressure generally needs to be higher.

#### 4. Binding Strap System

Generally, they are used jointly with compensation and space or anti-load clothing (see charts 2-19 and 2-20). Binding strap systems are very important in raising endurance to back → overweightness. When a person is subjected to over 4 G back → chest overweightness, the head bends toward the chest and cannot be lifted up. At this time, pilots cannot carry out observation and control. The use of a binding strap system to fix the head can allow the head to remain vertical under any overweightness. Under back → chest overweightness, pressure is increased on the safety belts for the chest and abdominal areas. Common safety belts are not suitable and it is necessary to use specially made binding straps to prevent the arms from going forward.. The use of a good binding strap system for chest → back overweightness

can be used to maintain the body in a good posture so as to raise the effects of endurance.

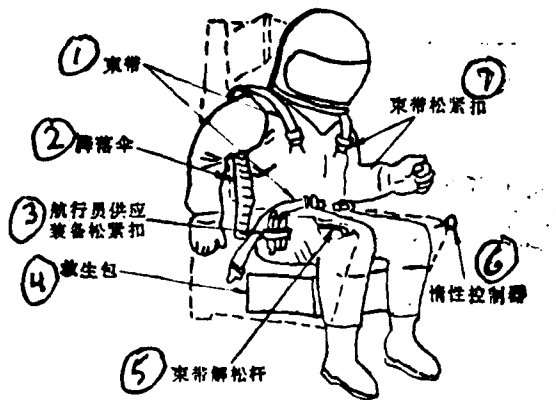


Chart 2-19 The Combined Use of a Binding Strap System and Space Clothing

1. Binding straps
2. Parachute
3. Navigator's supply equipment tightening buckle
4. Lifesaving bag
5. Binding strap release rod
6. Inertial controller
7. Binding strap tightening buckle

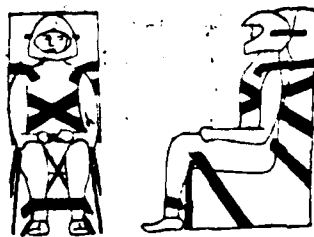


Chart - 2-20 The Use of Binding Straps as Protection Against Overweightness

To prevent shifting, different straps are needed for each part of the body which is shown in chart 2-21. When overweightness is greater than the numerical values shown in the chart, if

there is no binding strap protection, then that part of the body will have difficulty moving in the direction of the arrows shown in the chart.

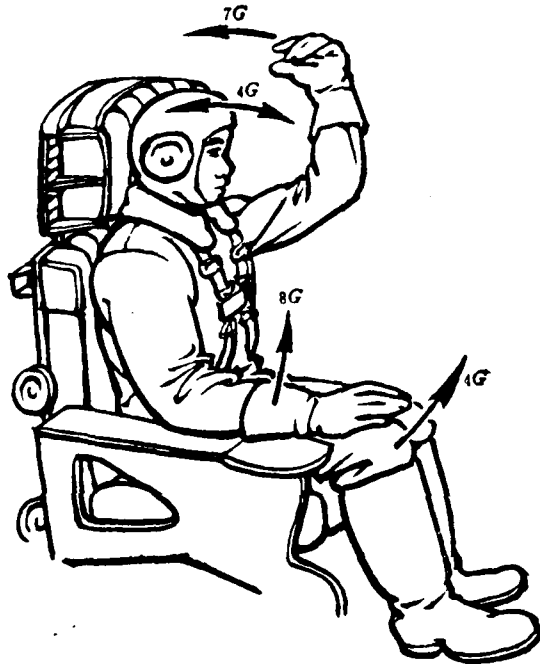


Chart 2-21 The Effect of Overweightness on Operating

#### 5. Form Fitting Couch Equipment

The use of a couch that contours to the human shape to maintain the body in a fixed posture can, to a large extent, raise a person's endurance to overweightness. Its advantages are:

- (1) it causes the body to maintain the best posture;
- (2) it causes the pressure on an area to be evenly distributed and that area to be in contact with the soft couch;
- (3) it decreases muscle shifts;

- (4) for the pressure on the limbs caused by overweightness and which presses on the peripheral blood vessels, the form fitting couch impels the blood to flow back into the heart.

A good form fitting couch can allow a person to endure 25 G chest → back overweightness for 40 seconds. Chart 2-22 is a model of a form fitting couch.

The posture of the form fitting couch shown in the chart has the legs slightly higher than the level of the heart and head so that under 10 G overweightness, a person can still maintain consciousness because the hydrostatic pressure difference is not large, equal to about 72 millimeters on the mercury column. At this heart level, carotid artery pressure is 120 millimeters on the mercury column and this can effectively supply blood to the brain. Therefore, the form fitting couch shown in the chart can raise endurance to chest → back overweightness to 6-8 G for 4-5 minutes, to back → chest to 6-8 G for 4-5 minutes and to positive overweightness to 6-8 G for 3-4 minutes. When exposure time is relatively short, the effects of anti-overweightness can be even higher. After the use of these form fitting couches, when a person is under 6 G back → chest overweightness and 12 G chest → back overweightness, they can very naturally complete spaceship and aircraft control tasks.

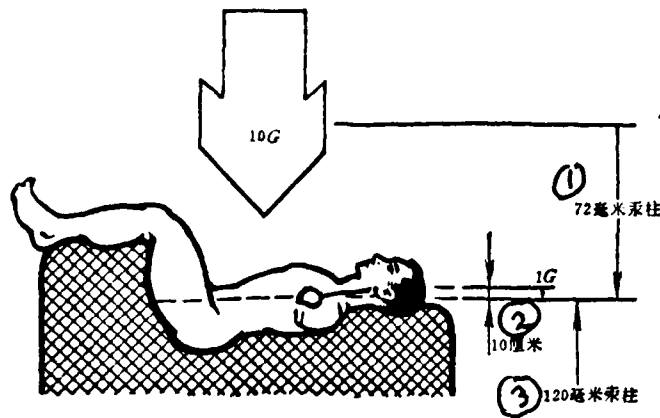


Chart 2-22 The Use of a Form Fitting Couch and the Effect of Adopting a Suitable Body Posture for Protecting the Body Against Horizontal Overweightness

1. 72 millimeters on the mercury column
2. 10 centimeters
3. 120 millimeters on the mercury column

A netted couch is a net structured soft couch made from nylon rope. It is said to be able to raise endurance to overweightness by 1.7 G, yet because it effects control movements, at present it is still not being used.

Aside from this, there is also the changing posture seat. This type of seat can change in the direction of the overweightness and when overweightness exceeds a specific numerical value, it automatically changes the posture thus raising endurance.

#### 6. Regulating Respiration of Gases

##### (1) Pressor Respiration

Chest → back overweightness causes increased pressure on the chest which brings about respiration difficulties. The use of pressor respiration can sometimes more than double endurance. A type of airtight helmet can also be used for negative overweight-

ness and pressurized air is fed into the helmet. The use of this type of helmet can tighten hyperemia in the face area, headaches and acceleration of the heart rate.

(2) The Breathing of Pure Oxygen and Pressurized Supply of Oxygen

The breathing of pure oxygen can raise endurance to overweightness and the effects of pressurized supply of oxygen are even better. However, the pressure of pressurization must be equal to the numerical value of the overweightness and approximately for each increase of 1G, the pressure should increase 17.5 millimeters on the mercury column. It is necessary to take care that the time not be too long, for when the time is too long, it can create oxygen poisoning (see chapter 14 on oxygen poisoning).

(3) Raising Carbon Dioxide Concentration in Respirated Gases

Some people have discovered that breathing air with 4-6% carbon dioxide can raise endurance to positive overweightness about 0.5 G, but the reason for this has still not been explained.

7. Training for Overweightness

Practical experience in space navigation has proven that training for overweightness is very significant for raising endurance to overweightness. After complete training on the ground and in the air, endurance to overweightness can be raised tremendously.

Regular physical training such as cartwheels, swinging, somersaults, single and double parallel bars, mountain climbing, gymnastics, sprinting etc., as well as training in the centrifuge

and other physical excersisers are advantageous to raising endurance to overweightness. Stunt flight training is naturally even more of an aid to raising endurance. However, it is necessary to stress that training in overweightness cannot be excessive and if it is done to the extent of harming one's health it will cause endurance to lower. From a medical standpoint, this is absolutely not permissable.

In training, it is also necessary to stress the revolutionary optimistic spirit and revolutionary will of the trainee so that they are able to bear great hardships, stand hard work, maintain confidence in times of difficulty and emergency and put forth great effort to give full play to their subjective activities. This is not only necessary for conquering overweightness and other various non-advantageous factors, but they are also important measures for training pilots and astronauts of good quality.

#### 8. The Combined Use of Various Protective Measures

The various protective measures previously mentioned each have their advantages. Chart 2-23 shows the different sizes of several protective measures for raising endurance to overweightness and the endurance time is used to indicate it.

It is best to use the various protective measures in combination so as to gain the coordinated effect of joint action. To jointly utilize several types of protective measures it is only necessary that there are no contradictions between the actions of each measure and then, without a doubt, this will be



able to raise endurance to overweightness. Citing an example can illustrate the problem. For example, when anti-load clothing is worn and the angle lying on the back is  $17^\circ$  or  $10^\circ$ , if added effort is given to increasing muscle tension and a binding strap system is further added to support side expansion of the chest, this can cause a person's endurance to horizontal overweightness to be raised to 20 G and the total action time to be 54 seconds. Furthermore, if at the same time the lying on the back posture is  $10^\circ$ , one breaths pure oxygen and a form fitting couch is used, then endurance to horizontal overweightness can be raised to 22 G for 50 seconds and 26.5 G for 8 seconds.

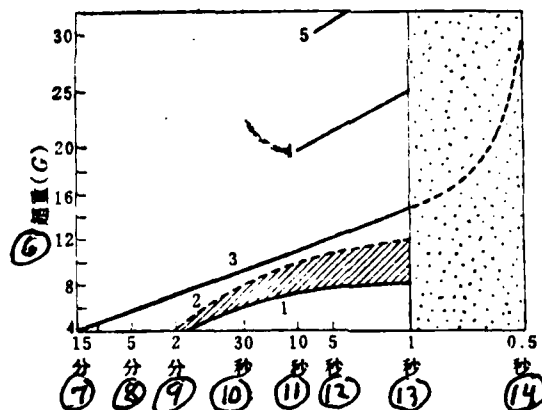


Chart 2-23 The Use of Several Types of Protective Measures for the Human Body to endurance Overweightness

1. Endurance without protection
2. Endurance limit in orbital flight
3. A person's endurance to overweightness when the best aircraft seat is used
4. A person's endurance when a form fitting couch is used
5. A person's endurance when immersed in water

The striped area on the right side of the chart represents a person's endurance to the impact of overweightness when the best

aircraft seat is used.

6. Overweightness (G)
7. 15 minutes
8. 5 minutes
9. 2 minutes
10. 30 seconds
11. 10 seconds
12. 5 seconds
13. 1 second
14. 0.5 seconds

## CHAPTER FIVE

### HARMFULNESS OF VIOLENT IMPACT AND AIRFLOW SHOCKS

#### Section One - Preface

Impact points to the impact of the human body with certain substances and in most situations is the result of a sudden slowing down from a very high speed. The physiological effect of deceleration is overweightness. The special features of impact overweightness are that the time is short ( $< 0.3$  seconds) and the numerical value is great. Therefore, the growth rate of overweightness is very high.

Impact is possible in aircraft and spaceships and most often occurs at the time of accidents. Yet, sometimes, it also occurs under normal situations. Generally, when an aircraft or spaceship is landing normally there is a specific level of impact but the impact is at a level endurable to the human body. In parachuting from an aircraft, when the parachute opens and the human body touches the ground, light impact occurs and when ejecting from an aircraft, the impact overload is relatively stronger and can even imperil life. This type of impact is created at great acceleration. The conditions of several types of frequently observed impact and their overweight values are listed in charts 2-24 to 2-26.

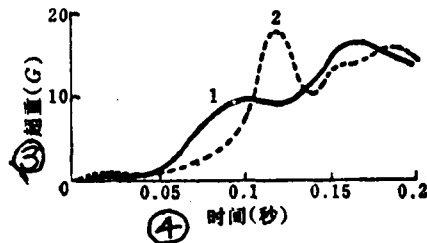


Chart 2-24 The Overweightness Process of Experimental Ejection

1. Determined value of seat position
2. Determined value of buttocks
3. Overweightness (G)
4. Time (seconds)

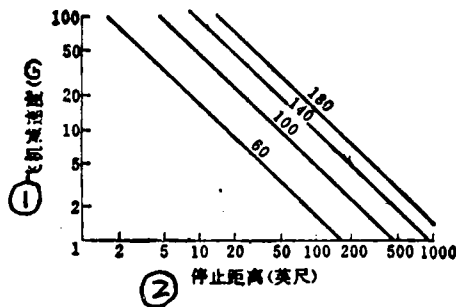


Chart 2-25 When an accident occurs during takeoff or landing there is a relationship between the numerical values of aircraft speed, stopping distance and deceleration (overweightness) - (the numerical value on the curves indicates aircraft speed and the unit is nautical miles/hour).

1. Aircraft deceleration (G)
2. Stopping distance (feet)

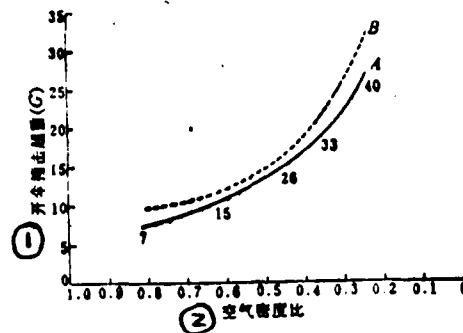


Chart 2-26 The Impact Overweight Numerical Value. When the Parachute Opens at Different Altitudes (Results of Human Body Model Tests)

- A - Nylon parachute with 28 foot diameter used
- B - Nylon parachute with 24 foot diameter used

The numbers on the curves indicate the different parachuting altitudes (1,000 feet). Aircraft air speed was fixed at 115 nautical miles/hour.

1. Impact overweightness when parachute opens
2. Air density ratio

Below we will briefly describe the general circumstances of landing impact and ejected parachute impact.

#### 1. Landing Impact

Generally, when an aircraft or spaceship touches down there is a light degree of impact. The landing speed of an aircraft is 3 meters/second, impact overweightness when touching down is 38.5 G, the time is 0.03 seconds and the overweight growth rate is 5,480 G/second. When landing speed is 6 meters/second and impact overweightness is 40-60 G, the overweight growth rate is 5-8 thousand G/second. A spaceship's best landing speed is 7-9 meters/second and

when sometimes it reaches 20-30 meters/second it is necessary to observe whether the landing is on the ground or on water as well as the meteorological conditions. Water can sustain a greater impact force and therefore the landing speed on water can be greater. The larger the landing speed, the larger the impact overweightness and the greater the possibility of harm to the human body. For this reason, it is best for spaceship landing speed not to exceed 12.2 meters/second. However, for the human body the impact of this type of landing speed is quite large. For safety, besides lowering landing speed as much as possible, it is also necessary to utilize protective measures, for example, the use of a landing cabin, a spring mattress seat and braking equipment.

## 2. Ejection and Parachute Impact

When aircraft speed does not exceed 150 kilometers/hour, a pilot can voluntarily parachute out of an aircraft. When the speed is over 250 kilometers/hour, parachuting is difficult and technical training is required to be able to complete it. When the speed is greater than 400 kilometers/hour, it is impossible for a pilot to complete parachuting by himself. If he is able to jump out, there will be the danger of impact with the aircraft tail. Because of this, it is necessary to use an ejection system to be able to leave the aircraft. Ejection is the firing of a shell or rocket from a tube below the seat. Modern parachuting and ejection equipment have relatively complex automatic devices so that after the pilot switches the button on, all of the steps are carried out automatically and this guarantees

safety. Emergency equipment in modern aircraft should at least be able to guarantee ejection at an altitude below 25,000 meters and at an air speed of 300-1,200 kilometers/hour. Yet, up to now, there have been many accidents in ejection and parachuting that have resulted in injury and death. This is not a problem in engineering technology but most are due to human errors. Based on statistics from many countries, the rate of occurrence of parachuting and ejection injuries is 10-30%. The injuries are mainly due to impact overweightness. Therefore, impact and protection against it are very important problems for safety in ejection and parachuting.

The ejection and parachuting process can be divided into the following several stages: (1) emergency preparations in aircraft; (2) ejection from an aircraft; (3) free fall before the parachute opens; (4) parachute opens; (5) falling with parachute; (6) touching ground. In stage (2), deceleration impact and air-flow impact are sustained when ejecting, in stage (3) there is the possibility of going into high speed rotation or somersaults. In stages (4) and (5), it is also possible to encounter impact, that is the impact of the parachute opening and the impact at the moment when touching down on the ground. In the stages that have impact overweightness and rotation and somersaults, a person's physiological reactions are more violent and there is the highest chance of danger. Chart 2-27 shows the changing process of the heart rate and respiration rate when parachuting.

It can be seen from chart 2-27 that in periods ⑤ and ⑦, the action of shock overweightness causes the heart rate and respiration rate to rise.

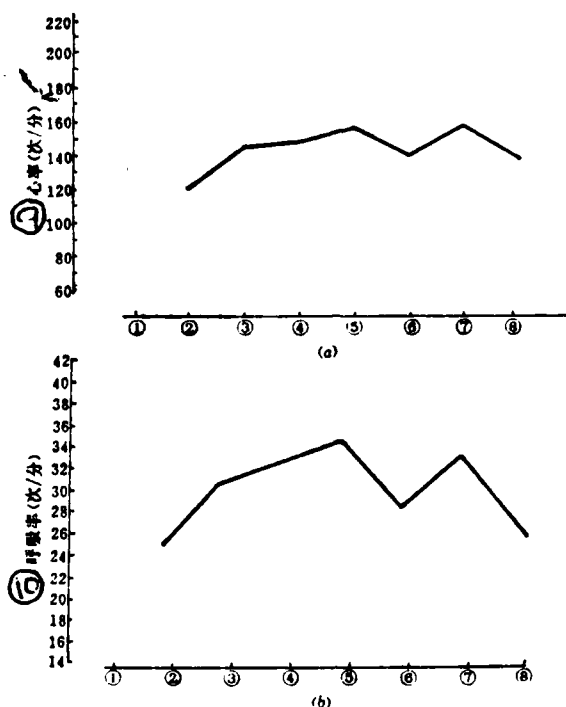


Chart 2-27 Heart Rate (a) and Respiration Rate (b) in the Ejection and Parachuting Processes

1. Comparative values when sitting normally
2. Numerical value when sitting in an aircraft
3. Numerical value when parachuting
4. Numerical value in free fall
5. Numerical value when parachute opens
6. Numerical value when falling with parachute
7. Numerical value when landing
8. Numerical value after landing
9. Heart rate (times/minute)
10. Respiration rate (times/minute)

The main dangers in ejection and parachuting are:

- (1) the impact injury when ejecting or leaving an aircraft;
- (2) impact overweightness and airflow shock injuries when ejecting: if it is raining when one is ejecting it is also possible to be harmed by raindrops;
- (3) injuries from the impact of a parachute opening (because in free fall when the human body gains a great deal of speed and suddenly there is deceleration from the parachute opening, impact overweightness can occur;



#### (4) injuries from landing impact

To avoid the last of these types of impact injuries, the most suitable landing posture should be adopted. Chart 2-28 shows several good and bad postures for parachute landing.

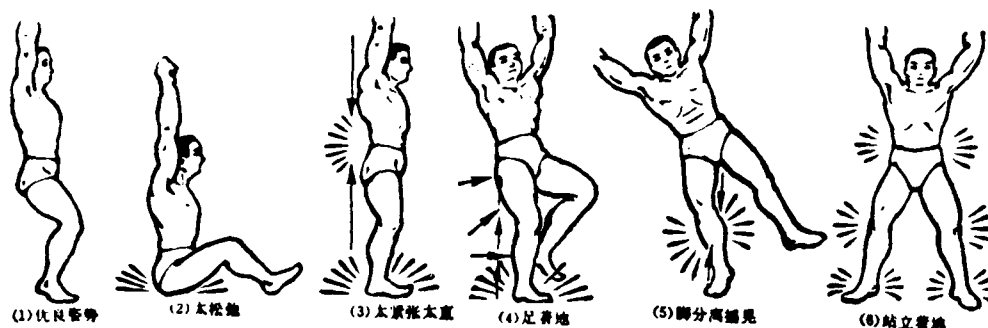



Chart 2-28 Good Posture (1) and Bad Postures (2-6) For Parachute Landing

- (1) Good posture
- (2) Too relaxed
- (3) Too tense and too vertical
- (4) Foot touches the ground
- (5) Feet separated and shaking
- (6) Standing erect touching the ground

[Note]: In the chart  indicates the impact injury is produced.

Another problem to pay attention to is that the body is an elastic system and has elastic dynamic reactions. Therefore, an impact overweightness even greater than the seat is often produced during ejection. This is called "overweightness surpassed". When using an elastic seat cushion, this overweightness surpassed phenomenon is even more severe and the curves shown in chart 2-29

are the observed results of certain of these phenomena. In the chart, the solid line area is greater than that of the dotted line and so is the "overweightness surpassed". Overweightness in the ejection process which surpasses human body endurance, is one reason for injuries.

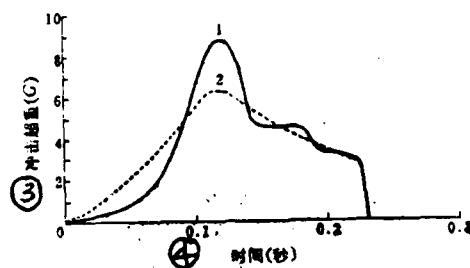


Chart 2-29 The Impact Overweightness Measured from a Subject's Shoulder (1) and Seat (2) in a Downward Ejection Test

- 3. Impact overweightness (G)
- 4. Time (seconds)

## Section Two Head Impact Injury and Endurance

The harm of impact to the human body and its action area, direction and time as well as the person's posture are all related. When a person is seated, the danger of head impact is greatest. The harm of impact to the human body is determined by the numerical value (the unit is G) and time (seconds) of impact overweightness. When impact is less than 1 millisecond, the limit of head endurance (which does not cause the skull to crack) is 300-400 G. Yet, the head can only endure 70-80 G when impact lasts 30-40 seconds. When greater than this value there can be

cracking of the head. Commonly observed impact time is 3-4 milliseconds and the skull's effective endurance load is 100 G.

If there is no skull cracking when the head sustains impact a series of pathological symptoms can be produced because of a cerebral concussion which is due to violent shifts of the brain in the skull. Endurance to head impact cerebral concussions is related to the natural concussion period of the human brain.

Head impact injuries are not only determined by the size of impact force and the time and course of the impact, but they also depend on the impact area and the shape of the impact substance. For example, a pointed object can stab into the skull with little impact and become a dangerous injury. Impact injuries by smooth and relatively large objects are smaller. If reinforced plate glass is in front of the face, when the head collides with the plate glass this can cause the glass to smash and the head to go through to the outside of the window. This can possibly cause no injury or perhaps just a small injury. However, if the head collides with relatively thin plate glass, this can cause the head to go into the smashed glass wherein the glass pieces will cut and draw blood from the soft tissues in the head, face and neck.

To estimate the force (overweight threshold value) which caused a serious head impact injury, we could not directly use people for testing. Because of this, we could only obtain reference numerical values from impact accident cases that had already happened. Some ten people have shown temporary loss of

consciousness after impact but did not suffer any serious injury. When the patients were examined, it was discovered that they had suffered the impact of an object 3-5 centimeters in diameter and that its impact overweightness was between 115-<sup>450</sup> G. Because they had already come close to a serious injury, the above mentioned numerical value could act as a reference for the serious harm created by head impact. Chart 2-30 is an illustrated investigative summary of 3,000 cases of cerebral concussion. The relationship of their initial and later symptoms and the force of the impact are really worth consulting. In the chart,  $V$  is the impact speed (meters/second); the black areas in the middle of the circles indicate the patient's condition; the oblique line areas indicate that the patient's condition is not good; the blank areas show that the condition is good. The skull drawings show the injured areas and the number outside the circles indicate the percentage each of the various injuries occupies.

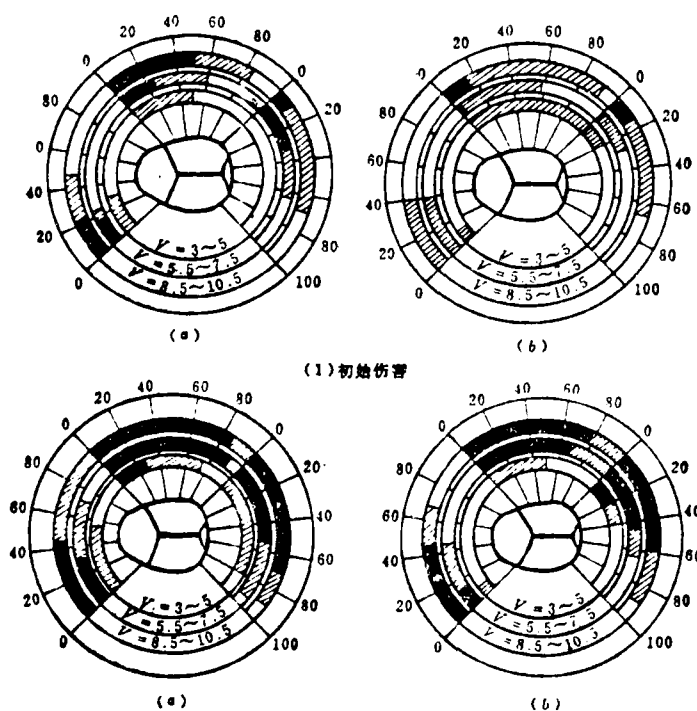


Chart 2-30 Head - Impact - Injuries

- a. Touchdown injury when there was no protection
- b. Touchdown injury when wearing a helmet
- (1) Initial injury
- (2) Just after injury

Prior to head impact reaching serious injury, there is usually the feeling of not being able to endure the impact. Because of this, the major endurance limit of head impact is much lower than the threshold value of a serious injury. Table 2-14 shows the major endurance limit of the head impact (when wearing a helmet) when a hammer is used to hit the head. It can be seen from the table that the major endurance limit of a

person's head to local impact is about 20 G and the overweight growth rate is 3,500 - 5,600 G/second. The major limitations to endurance are local contussions and pains, neck tie area pains and general discomfort. The secondary limitations are cervical vertebra pains and general head pains.

	① 頂 击	② 前 击	③ 側 击	④ 后 击
⑤ 碰撞速度(米/秒)	1.7	1.5	1.7	1.6
⑥ 碰撞力(公斤·厘米)	54	37	51	44
⑦ 碰撞超重(G)	23	22	20	18
⑧ 碰撞超重增长率(G/秒)	4800	5600	3500	3700

Table 2-14 Major Endurance Limitations of Human Head Area (Wearing a Helmet) to Impact

1. Top impact
2. Front impact
3. Side impact
4. Back Impact
5. Impact speed (meters/second)
6. Impact force (kilograms, centimeters)
7. Impact overweightness (G)
8. Impact overweightness growth rate (G/second)

### Section Three General Injuries of Impact on the Whole Body

The physiological effects of impact on the whole body are injuries caused by violent impact and occur mainly in the heart, musculoskeletal system. Its main symptoms are acute pains in the heart and chest-abdominal area, headaches and muscle and joint pains in the neck, heels and knees. Clinical examinations have expanded this to fractures, muscle and skin injuries, blood spots, muscle tension and weakness, heart and intracranial hemorrhaging, cerebral shaking and even shock and death. Under relatively light impact, the heart rate and respiration rate quicken and under

severe impact these rates lower or weaken. The heart shifts which occur during impact are also important physiological reactions.

Table 15 summarizes the symptoms and physiological effects of impact on the whole body and thus shows the general picture of the physiological effects of impact on the whole body.

① 实验设备	② 冲击方向	③ 冲击超重情况			⑦ 症状
		④ 峰值超重(G)	⑤ 超重增长率(G)	⑥ 作用时间(秒)	
⑧ 坠落塔	⑩ 足 ↓ 头	13.4~17.2	750~1770	0.58~0.66	⑨ 轻度头痛, 无其它症状
		⑫ 头部17.2	⑬ 最大1950 ⑭ 平均850	0.90	⑨ 肩胛部位刺痛, 但立即消失; 碰撞后活动正常, 神志清醒, 心电图窦性心动过速
		17.7~23.8	386~3170	0.67~0.82	⑨ 前额、右斜方肌、左耳上方头骨和颈部疼痛, 肘部皮伤
		18.8~26.6	495~1800	0.84~0.93	⑨ 吃惊, 头痛, 小腿肌痛, 胸骨下痛, 扩散性痛, 未见严重创伤
		⑮ 头部18.8	⑬ 最大5080 ⑭ 平均1230	0.57	⑨ 突然剧烈的前额痛, 臀部刺痛, 碰撞后15秒消失。未见运动障碍, 心电图窦性心动过速
		⑮ 头部21	⑬ 最大2060 ⑭ 平均872	0.08	⑨ 较大的臀部不适, 下落时感到臀部上升, 碰撞时有臀部碰撞硬物之感, 碰撞后动作良好, 神志清醒, 心电图窦性心动过速
⑨ 秋千	⑪ 垂直向	35	—	几分之一	⑨ 血尿持续达一个月
		⑮ 速度变化	⑬ 4.44米/秒	0.10	⑨ 小腿和躯干下部刺痛, 有时出现一时性胸骨下痛和后头痛, 肝部位移4厘米, 已接近主诉可耐限
⑨ 秋千	⑪ 垂直向	⑮ 腹部4~22	—	0.001~0.001	⑨ 腹部和消化道疼痛

Table 2-15 Physiological Effects and Symptoms of Impact on the Whole Body

1. Test equipment
2. Impact overweightness conditions
3. Overweightness direction
4. Peak value of overweightness (G)
5. Overweightness growth rate (G)
6. Action time (seconds)
7. Symptoms
8. Sunken tower
9. Swinging
10. Foot + head
11. Horizontal
12. Head area 17.2
13. Head area 18.8
14. Head area 21
15. Speed changes

16. Abdomenal area 4-22
17. Largest 1,950
18. Average 850
19. Largest 5,080
20. Average 1,230
21. Largest 2,060
22. Average 872
23. 2.44 meters/second
24. Light pain at the top of the head, no other symptoms
25. Acute pains in shoulder area, yet they immediately disappear; after impact, movements are normal, there is full consciousness, electrocardiogram sinus tachycardia
26. Pains in the forehead, right oblique muscles, left ear upper skull and neck area and elbow skin injury
27. Chills, headaches, shank muscle pains, pains below sternum, spreading pains, no serious injury
28. Sudden acute forehead pains and sharp pains in the buttocks disappear 15 seconds after impact. There are no movement obstructions, electrocardiogram sinus tachycardia
29. Relatively large discomfort in buttock area, when descending there is the feeling that the buttocks are rising, when there is impact there is the feeling of the buttocks colliding with a hard object, after impact movement is good, there is full consciousness and electrocardiogram sinus tachycardia
30. Blood in the urine continues for one month
31. Sharp pains in shank and torso, there sometimes appear temporary pains below the sternum and pains in the back of the head; the liver shifts 4 centimeters and approaches major endurance limit
32. Pains in abdominal area and digestive tract

Section Four Injury and Endurance of Vertical Impact on the Whole Body

Vertical impact on the whole body during ejection, when the parachute opens and landing is relatively hard, there is sizeable injury to the vertebra and the after effects are quite severe. Using ejection as a basis for analysis, the occurrence rate of vertebra injury reaches to about 43% and most of the



injuries are to the vertebra in the lower thoracic area. For the relationship of acceleration speed and its action time causing vertebra injury, see chart 2-31.

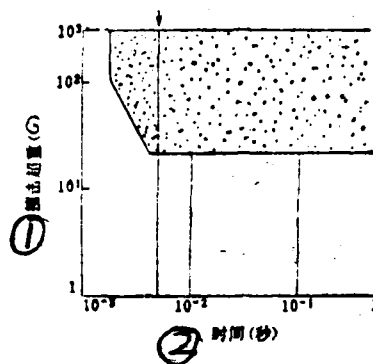


Chart 2-31 Static Endurance (the right side of ↓) and Dynamic Endurance (the left side of ↓) of the Human Vertebra

In the chart, the black spotted area indicates non-endurance.

1. Impact overweightness (G)
2. Time (seconds)

Endurance to vertical impact is closely related to a person's posture. The situation is shown in chart 2-32. This chart can be viewed as the safety endurance limit of a person falling in a seated posture. In the chart, the black area is the impact overweightness numerical value and the oblique line area is the determined impact overweightness numerical value of the shoulder area. The endurance limitations are: (1) severe pains (chest vertebra, head, abdominal area); (2) shock (medium to heavy degree).

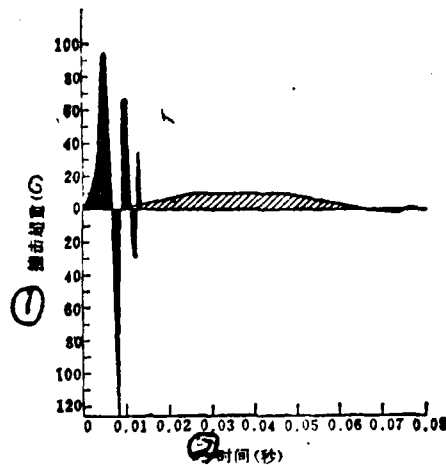


Chart 2-32 Endurance to Vertical Impact in a Seated Posture  
(Seated in a Hard Chair)

1. Impact overweightness (G)
2. Time (seconds)

Most of the cases of injuries sustained in high altitude falling occurred in the feet, buttocks and head area upon touching down on the ground and these injuries were relatively serious. The injuries sustained in the hands, knees and side of the body upon touching down were relatively light and injuries suffered from falling on the back were smallest in number.

Chart 2-33 shows that the endurance limit and injury threshold value of impact overweightness when ejecting upwards can offer a precise safety range and reference for engineering design.

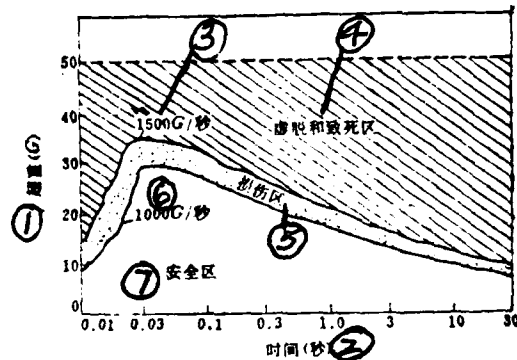


Chart 2-33 Endurance and Safety Range of a Person to Upward Ejection Overweightness During Ejection

1. Overweightness (G)
2. Time (seconds)
3. 1,500 G/second
4. Collapse and death
5. Injury area
6. 1,000 G/second
7. Safety area

Why is endurance to vertical impact closely related to the posture of the human body? There are two major reasons:

- (1) overweightness is closely related to the body's physiological effects and posture which has already been detailed in chapter two;
- (2) the vertebra's ability to sustain impact is closely related to the posture of the torso

The normal state of the vertebra is not perfectly straight but is double curved. Because of this, when there is up to down action on the vertebra, there are differences in the sustained force on each of its sections. When the sustained force is large it is easy to suffer injury and in weak places, even if the sustained force is equal, it is still easy to suffer injury. When the vertebra is in an erect posture, the greatest impact area is

on the vertebra and this can sustain the greatest force. Even if there is 30 G overweightness with a growth rate of 500 G/second, there will still be no injury. On the contrary, if the body bends forward and causes the vertebra to be arched, then 9-14 G overweightness with a growth rate smaller than 500 G/second can cause sphenocracks in the first and second lumbar vertebra. The lumbar vertebra inclines forward and when the front edge of the vertebra is subjected to a concentration of negative overweightness, fractures occur.

If the posture is suitable and there is also solid helmet equipment and shoulder straps, then a person can endure 33 G impact overweightness with a growth rate of 500 G/second. For absolute safety, jet fighter upward ejection cannot exceed 20 G and action time is limited to within 0.1-0.2 seconds. The greatest overweightness for downward ejection when the growth rate is 200 G/seconds cannot exceed 10 G. Supersonic aircraft use rocket ejection or rocket and shell combined and the action time is extended to over 0.25 seconds. Because of this, the highest endurable G value can decrease so that the limit for upward ejection can be 18 G/0.25 seconds. When rocket ejection is used, the G value growth rate is relatively slow and therefore the peak value of endurance to overweightness does not necessarily decrease. However, there is still no final solution to this problem.

Upward ejection most easily causes vertebra injury and therefore past research has concentrated on how to strengthen vertebra erectness and cause the head to be fixed. The seat binding strap systems in modern supersonic jets are all for the

purpose of fixing the body, head and feet so as to raise endurance to ejection and to avoid injury. Besides demanding safety and unobstructed ejection movement, people have also researched automatic shoulder straps and elastic seat cushions, attempted to make the upper body erect and shifted the buttocks back in order to raise endurance.

Downward ejection is used in different places in large scale jet bombers and transport planes. Downward ejection is not limited by wing altitude and therefore ejection power can be relatively small. Only because blood shifts can cause the head to fill up with blood, bring about carotid sinus reflex and easily cause coma, the highest G number must not exceed 10 G (presuming the action time reaches 0.5 seconds). If it does, then there is the danger of red vision and loss of consciousness.

#### Section Five The Effect of and Endurance to Horizontal Impact

Endurance to horizontal impact on the whole body is higher than endurance to longitudinal (vertical) impact and it is also greater than the body's endurance to horizontal overweightness. When an aircraft or spaceship collides with an object, when the human body carries out horizontal ejection and when a spaceship returns and opens its parachute, there are the possibilities of encountering horizontal impact. The illustrations in charts 2-34 and 2-35 show the endurance to horizontal impact.

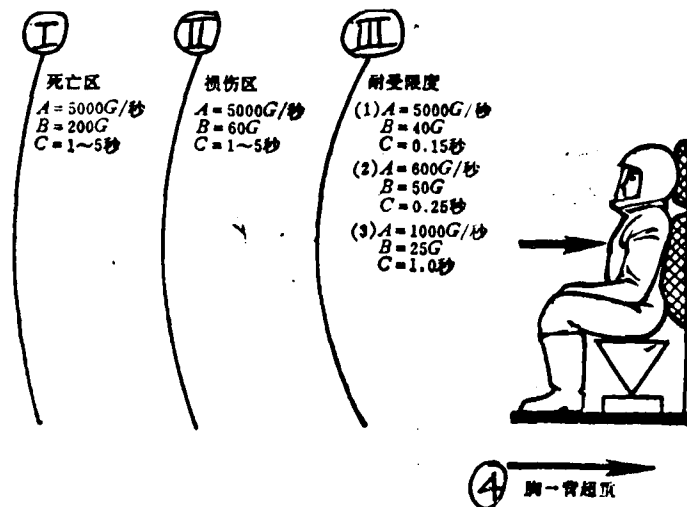


Chart 2-34 The Endurance Range to Chest → Back Overweightness in a Seated Posture (Based on Rocket Test Results)

- A. Deceleration growth rate
- B. G peak value
- C. Action time

Data on injury and death is based on the results of tests on large Animals.

- I. Death area
  - $A = 5,000 \text{ G/second}$
  - $B = 200 \text{ G}$
  - $C = 1-5 \text{ seconds}$
- II. Injury area
  - $A = 5,000 \text{ G/second}$
  - $B = 60 \text{ G}$
  - $C = 1-5 \text{ seconds}$
- III. Endurance limit
  - (1)  $A = 5,000 \text{ G/second}$   
 $B = 40 \text{ G}$   
 $C = 0.15 \text{ seconds}$
  - (2)  $A = 600 \text{ G/second}$   
 $B = 50 \text{ G}$   
 $C = 0.25 \text{ seconds}$
  - (3)  $A = 1,000 \text{ G/second}$   
 $B = 25 \text{ G}$   
 $C = 1.0 \text{ seconds}$

4. Back → chest overweightness

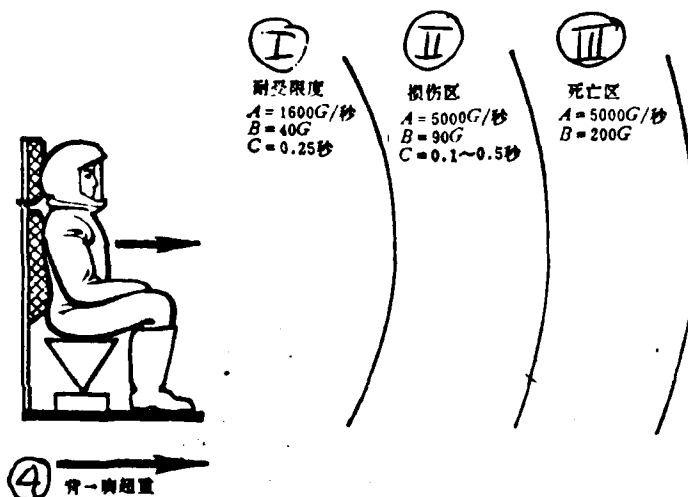


Chart 2-35 The Endurance Range to Back + Chest Overweightness When in a Seated Posture (In the Chart, Data on Injury and Death is Based on Inferences from Rocket Tests on Animals)

A. Deceleration growth rate  
B. G peak value  
C. Action time

I. Endurance limit  
A = 1,600 G/second  
B = 40 G  
C = 0.25 seconds

II. Injury area  
A = 5,000 G/second  
B = 90 G  
C = 0.1 - 0.5 seconds

III. Death area  
A = 5,000 G/second  
B = 200 G

4. Back → chest overweightness

Generally speaking, when impact is greater than 50 G, the growth rate exceeds 500 G/second and the action time is longer

0.25 seconds. This can cause a large or small amount of injury symptoms and indicates that the highest endurance limit has already been surpassed. However, when impact is 40 G with a growth rate of 500 G/second and action time is less than 0.2 seconds, this can be viewed as the greatest endurance limit to horizontal impact overweightness and therefore the safety range is below this limit.

At the low speeds of common safe landings and lateral ejections, overweightness is below this endurance limit. Based on the rules of landing after parachuting from an aircraft, landing speed cannot exceed 6 meters/second and lifesaving bag and spaceship landing speed cannot exceed 8 meters/second. The latter two both have cushion shockproof equipment and, therefore, if this type of landing speed is used and the deceleration G number is very low, landing is completely safe.

Simulated aircraft and spaceship tests on landing impact have shown that when the descending landing speed of an aircraft or spaceship is below 6 meters/second, then there will not be any bodily threat no matter what the impact. With the use of a form fitting couch, endurance is even higher. With good binding strap protection a person can very well sustain longitudinal impact overweightness of 15 G and horizontal impact overweightness of 60 G with an action time of 0.05 seconds.

## Section Six    Protection Against Impact

### 1. Helmet Protection

A helmet is a good assurance for protection against skull fractures



Firstly, the use of a helmet can distribute the impact load to a greater surface area so as to avoid the concentration of the load. Secondly, it can, as far as possible, extend the time of the impact thus lowering the transmitted peak value force. The first use mentioned above makes use of the hardness of the helmet's outer shell and the second makes use of the soft cushion on the inside of the helmet. However, the limitation of the size of the helmet does not allow the impact time to extend to over 50 milliseconds. Because of this, the use of a helmet is still unable to completely prevent cerebral oscillation. Binding straps should be used for the prevention of cerebral oscillation. This decreases the head angle shift during impact.

See Figure 2-36 for the circumstances of different types of impact to the head.

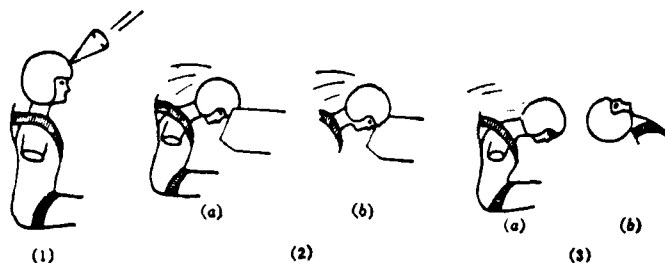


Fig. 2-36 Different types of impacts (a and b are subtypes)  
 1 - Sharp object strikes head; 2 - Flat object strikes head; 3 - Undergoing collision when overweight, head not impacting.

Figure 2-36 shows under type (1) impact conditions, the better the quality of the helmet, the better the effect of protection. Because impact force equals quality  $\times$  acceleration, the more the quality is increased, the more the acceleration value ratio shrinks; under b of type (2) impact, the heavier the helmet, the more beneficial it is. This is because the heavier the helmet the more beneficial it is in changing the shape of the impact object.

Yet, if the helmet's changed shape threshold value is lower than the impact object's changed shape threshold value, this will create injury. When a of type (2) impact is under the same impact acceleration (assuming the form of the impact object cannot be molded), the greater the helmet quality, then the greater the impact force on the helmet. This is because the quality of the helmet is combined with the weight of the person's neck. Under type (3) impact conditions (including a and b) an increase in helmet weight can cause larger injury. This is because under similar collision acceleration, the greater the helmet quality the greater the force on the joining area of the torso and neck. At this time, it is easy to incur injuries caused by excessive stretching of the neck.

Another problem worthy of attention in the field of helmet design is that the helmet should have a device to prevent it from falling off. This is because in ejection or falling accidents, there are many occurrences of the helmet falling off which is mainly due to the kinetic action of ejection and the violent tumbling in air. Thus, if the helmet is not tied tightly beforehand, it falls off easily.

In helmet design, aside from the need to consider its protective capabilities, it is also necessary to consider its effect on control. For example, a person's head can endure a weight of 1.8 - 2.3 kilograms for several hours (assuming the pressure is even and there is no pressure point) without sensing any pain. If the weight is increased, the head will feel pain and operation movements will be effected. If the distribution of the force is

not even, then even if the pressure point is not too heavy, under several hours of sustained weight there will be feelings of discomfort. If the weight of the helmet exceeds 1.8 - 2.3 kilograms and is used for more than several hours, the head and neck can feel tired and sore.

## 2. Elastic Seat, Binding Straps and Form Fitting Couch

When a person sits on an elastic seat, endurance to impact can be noticeably raised. The effects of a foamed plastic or foam rubber soft cushion are relatively good.

The use of an appropriate binding strap system can prevent internal organ shifts and lighten limb impact injuries. Chart 2-37 shows several examples of the use of binding straps to raise the human body's endurance to impact overweightness.

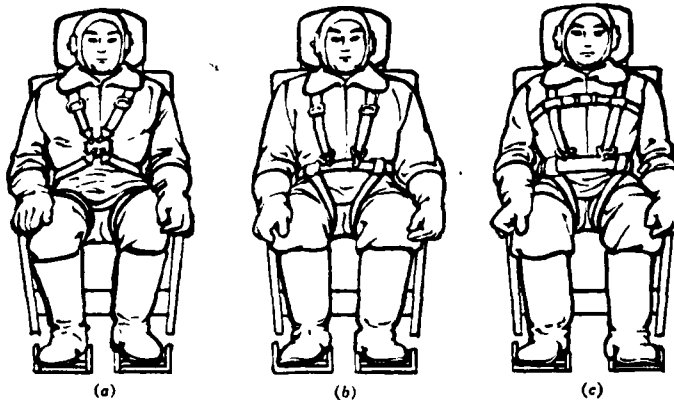


Chart 2-37 Three Types of Binding Strap Models for Fixing a Person in a Chair

- a. shoulder straps and waist straps connected
- b. shoulder straps, waist straps and leg straps connected
- c. shoulder straps, chest straps, waist straps and leg straps connecte

One of the major reasons for vertebra injury during ejection is that the person's head and body are bent forward.

Therefore, the binding strap design should consider the use of relatively tight shoulder straps and a back of a chair that reclines backwards to decrease this type of injury.

A form fitting couch which should be used in a spaceship is a relatively advantageous type of anti-impact equipment - see chart 2-22. It uses form fitting for the back area and a soft cushion with straps for the chest. A forward inclined posture of 55° above the horizontal level is used for the head and binding straps are used to fix it in place. Chart 2-37 which shows three types of binding strap models for fixing a person in a chair can be used for a form fitting couch but naturally it is necessary to make suitable adjustments. The protective effects of a form fitting couch are better than simple straps. The use of a 7.5 centimeter thick form fitting soft cushion is better than one that is 2.5 centimeters thick.

### 3. Suitable Postures

Man's endurance to horizontal overweightness is relatively high and his endurance to longitudinal overweightness is relatively low. This has already been discussed. In aircraft and spaceship design, the possibility of large impact to a person's transverse axis should be considered. The design of binding straps should take into consideration the possibility of correcting bad postures during impact so as to raise endurance.

### 4. Anti-Impact Equipment and Measures

To avoid the human body colliding with equipment in aircraft and spaceships, necessary measures must be considered for the

design structure so as to avoid a person's head and face colliding with pointed objects.

#### Section Seven    Airflow Shock

When a person is flying at high speed in the atmosphere, if they are suddenly ejected or parachute from the aircraft, they sustain airflow shock. The pressure of airflow shock is called "shock pressure" or "speed pressure" and can be calculated by the following formula:

$$Q = \frac{1}{2} \rho v^2 \quad (1)$$

In the formula,  $Q$  is the shock pressure,  $\rho$  is the medium (air) density and  $v$  is the medium (air) correct velocity.

Because of the different air densities at different altitudes, there are also differences in airflow shock pressure. For the different airflow shock pressures sustained by man when leaving an aircraft at different altitudes and speeds see table 2-16. Calculating from formula (1) and the data listed in the table, the following conclusions can be drawn: at an altitude above 12 kilometers, when a person ejects from an aircraft or spaceship at a flight speed of 2.4 M (speed of sound), sustained airflow velocity pressure reaches 5 tons/meter<sup>2</sup>. If the shock area on a person is 0.9 meters<sup>2</sup>, then the initial shock pressure is 6 tons. Assuming the weight of the human body after equipment is added is 162 kilograms, sustained weight is equal to 33.3 G. This type of shock overweightness decreases to under 5 G in about 1.5 seconds which is to say that it is equal to ten times the overweight value during a collision accident.

① 飞行速度(公里/小时)	② 气流冲压(吨/米 <sup>2</sup> )	③ 作用于人体上的压力(吨)
100~200	0.05	0.02
300	0.24	0.19
500	1.21	0.54
600	1.74	1.06
800	3.09	1.55
1000	4.76	2.90
1200	6.94	4.85
1300	8.15	—
1400	9.45	—
1500	10.9	—
2000	19.3	8.00

Table 2-16 Airflow Shock Pressure When Leaving an Aircraft at Different Flight Speeds

1. Flight speed (kilometers/hour)
2. Airflow shock pressure (tons/meter<sup>2</sup>)
3. Active pressure on human body (tons)

The major injuries of airflow shock pressure to the human body are in the head and there are sprains, fractures and dislocations of the four limbs when binding straps are not used. There is also tearing and bleeding sustained by soft surface tissues such as in the nose and mouth when there is very strong airflow. When airflow strength is greater than respiration power, air can charge straight into the nose and mouth and proceed to cause lung and stomach injury, especially the ripping of blood vessels. A pilot's individual equipment can also be blown away by the high speed airflow shock. Generally speaking, when the speed is 550 kilometers per hour and the airflow shock speed pressure is below 1,400 kilograms/meter<sup>2</sup>, this causes the forehead and face to change in shape and at 600 kilometers per hour with the airflow speed pressure above 1,700 kilograms/meter<sup>2</sup>, there is pain in the forehead and face and the chest feels pressurized. Airflow speed

pressure of about 2,600 kilograms/meter<sup>2</sup> (740-750 kilometers/hour) causes light injury to the head. Without any protection, when the speed is 750-800 kilometers/hour and airflow speed pressure is above 3,000 kilograms/meter<sup>2</sup>, shock to the face causes cracking, hemorrhaging and extravasated blood. Speeds of 1,100 kilometers/hour and speed pressure above 5,600-5,800 kilograms/meter<sup>2</sup> can cause bone fractures and dislocations and injuries to the internal organs (lungs, stomach etc.). Speeds of 740 kilometers/hour and airflow shock speed pressure above 2,600 kilograms/meter<sup>2</sup> can generally cause loss of motor abilities. Table 2-17 summarizes the effects of airflow shock on the human body and chart 2-38 shows the endurance of the human body to airflow shock superpressure.

Table 2-17. The effects of airflow shock on the human body

① 速 度	② 速 压	③ 症 状
④ 850~900 (公里/小时)		⑪ 短时间呼吸停滞, 通常伴有心电图窦性心律变化。当气流直接作用于头、面、上肢和下肢时最为不利。
	⑤ 70~180(克/厘米 <sup>2</sup> )	⑫ 下肢损伤
	⑥ 60~280(克/厘米 <sup>2</sup> )	⑬ 手部软组织损伤
	⑦ 3.5(吨/米 <sup>2</sup> )	⑭ 接近人的主诉可耐限
	⑧ 4.0, 5.2(吨/米 <sup>2</sup> )	⑮ 未出现伤害, 但主诉严重不舒适。心率加快, 心电图偏移, 血压升高。憋气, 肢体发凉, 眼球发红, 腿部的压力负荷很大, 腿痛, 活动受限制
	⑨ 5.5(吨/米 <sup>2</sup> )	⑯ 实验后面部发红, 而后转成白和紫, 呼吸气喘(每5~8秒一次), 两眼凸出, 上下眼睑膜充血, 左上眼皮外出漏血泡, 眼外面水肿。试验后短时间内主诉: 只能看见光点, 视野绿色, 很难睁开眼皮。肌肉骨骼衰弱, 难于支持体重。有时出现一时性神志不清、头痛、鼻血。面、鼻、胸、肩、颈部水肿, 肩和腿部出现伤痕和发凉, 活动能力大为减弱, 脉搏、呼吸减慢, 体温下降, 血压达休克水平
	⑩ 6.2(吨/米 <sup>2</sup> )	⑰ 实验后, 眼结合膜出血, 深度休克, 18小时后症状仍严重, 住院治疗达6个月之久

Table 2-17 (Key, next page)

1. Speed
2. Velocity pressure
3. Symptoms
4. 850-900 (kilometers/hour)<sup>2</sup>)
5. 170-180 (grams/centimeter<sup>2</sup>)
6. 260-280 (grams/centimeter<sup>2</sup>)
7. 3.5 (tons/meter<sup>2</sup>)
8. 4.0, 5.2 (tons/meter<sup>2</sup>)
9. 5.5 (tons/meter<sup>2</sup>)
10. 6.2 (tons/meter<sup>2</sup>)
11. Within a short period of time respiration stops and there are usually electrocardiogram sinus cardiac rhythm changes. Airflow action directly on the head, face and upper and lower limbs is the most harmful
12. Lower limb injuries
13. Soft tissues in the hand are injured
14. Approaches a person's major endurance limit
15. There is no appearance of injury, but there is severe discomfort. The heart rate quickens, the electrical axis of the heart shifts and blood pressure rises, suffocation, purple spots on the limbs, the eyeballs become red, the leg pressure load is very large, leg pains and movements are limit
16. After testing, the face becomes red and later becomes white and purple, there is respiratory asthma (once every 5-8 seconds), the two eyes protrude and there are blood spots in the upper and lower conjunctiva, blood bubbles outside the upper left eyelid and oedema around the eye. Within a short time after testing, it was stated that only light spots could be seen, peripheral vision was reddish brown and it was difficult to open the eyelids. Muscles and bones were weak and it was difficult to maintain body weight. Sometimes there occurs unclarity of consciousness, headaches and nosebleeds. There is odema in the face, nose, chest, shoulders and legs, the shoulders and legs show bruises and purple spots, motor ability is greatly weakened, the pulse and respiration become weaker, body temperature drops and blood pressure reaches the shock level.
17. After tests, the conjunctiva hemorrhaged, there was deep shock and 18 hours later the symptoms became serious so that it was necessary to be hospitalized for six months



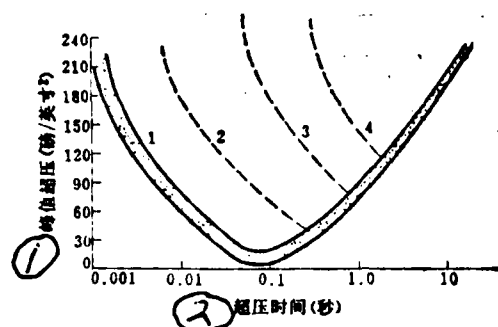


Chart 2-38 Endurance to Experimental Airflow Shock Superpressure

1. Peak value of superpressure (pounds/inch<sup>2</sup>)
2. Superpressure time (seconds)

In chart 2-38, the section below the grey area is the safety zone. The left border of the grey area follows the lengthening of superpressure growth time (superpressure growth speed becomes slower) and shifts to the right as shown by the dotted line in the chart. Curve 1 indicates that superpressure growth time is several tens of microseconds, curves 2, 3 and 4 separately indicate that following the lengthening of superpressure growth time, the endurance range has a great tendency to shift towards the left.

Modern ejection equipment has suitable guards, shock wave poles and face masks to prevent or lighten airflow shock or a small ejection cabin wherein the cabin and person are ejected together or the aircraft airshield and person are ejected together as a shield to the human body, or a spacesuit and good binding strap system are used to fasten the hands, feet and torso. Chart 2-39 is a type of ejection seat equipped with a shock wave pole.

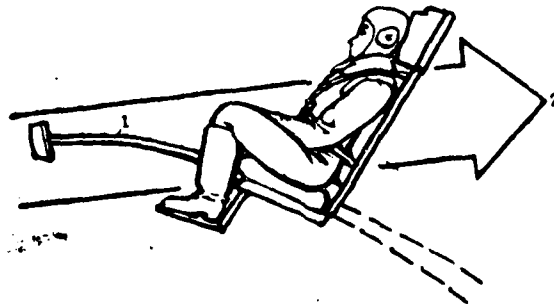


Chart 2-39 A Type of Ejection Seat Equipped with a Shock Wave Pole (Uses a Partially Deflected Airflow)

1. Shock wave pole
2. Airflow direction

Aside from this, some are designed with a decomposition (ejection) cabin so that when there is an accident the cabin and aircraft blow apart and thus the aircraft is allowed to fall and the cabin safely lands by means of a parachute. Some people think that this design is excellent and should be used in civilian transports.

## CHAPTER SIX

### HUMAN BODY REACTION TO VIBRATION

#### Section One Preface

From the point of view of physics, vibration is a type of periodic acceleration and deceleration and a type of specially shaped gravitational change. The action of vibration on the human body can be divided into local vibrations and whole body vibrations.

Local vibrations occur mainly in vibrating implements controlled by the hands (for example, the bit used in a large electric drill). Early, at the end of the nineteenth century, there were people who wrote about a type of hand occupational disease caused by long term use of vibrating implements. The symptoms were that the fingertips became white or purple, shook, became numb and burned. This especially appeared when it was cold and was called Raynaud's symptom. There are three general categories of hand and arm vibration disease:

- (1) tension changes in the blood vessels;
- (2) wrist and palm decalcification, as well as shoulder, elbow and wrist arthritis;
- (3) injury to soft tissues such as tendon contraction and thickening and the formation of cysts as well as ulna nerve injury

The above symptoms often occur when operating vibrating machines and implements and coldness of the whole body typically precedes it.

Aircraft workers use more high speed revolving implements whose resonant peak frequency is 166-833 cycles/second. There are differences between local hand vibration diseases caused by this and the symptoms mentioned above - the hand is often seen to be swollen and red. It is different from Raynaud's symptom and does not necessarily occur after feeling cold.

The more significant vibrations in aircraft and spaceships are whole body vibrations, not local vibrations. The highest section of vibrational energy lies in the low frequency range of under 200 cycles/second, especially vibrations of 1-10 cycles/second. This often has a greater effect on the human body. Chart 2-40 shows the frequency and strength of vibrations during launch.

Because low frequency whole body vibrations in aircraft and spaceships have a greater effect, this book focuses its narration on the effect of low frequency vibration on the whole body and the problem of protection against it while devoting less attention to local vibration

Vibrations act as a physical stimulant which includes frequency and amplitude. The former is the number of vibrations per second and is indicated by cycles/second or hertz and the latter is the vertical distance of the highest and lowest points in a sine vibration wave which is represented by the distance of the point away from the center between the two extremes. This is called peak - peak amplitude or double peak amplitude and is measured in millimeters. Vibration force is determined by vibration size and acceleration amplitude (uses G for measurement).

Chart 2-41 uses a linear graph to show the relation of the vibration frequency shift amplitude and acceleration amplitude in a sine vibration system.

Example: The dotted line in chart 2-41 indicates that the vibration frequency is 6 cycles/second and when its shift amplitude is 1 inch (semi-wave amplitude), the acceleration amplitude is 4 G. If we use a straight line to join the two points of a frequency of 6 cycles/second and a shift amplitude of 1 inch, the coordinate intersecting line is the acceleration amplitude numerical value.

The human body is an elastic system so that the physiological effects of different frequency vibrations are different and there is a noticeable effect of vibration direction on the body's physiological effects. Based on this, when explaining the effects of vibration on the human body it is necessary to cite its direction; when vibration is parallel with the head - foot axis it is called vertical vibration; when parallel with the chest - back axis it is called horizontal vibration; when parallel with the right - left axis it is called lateral vibration.

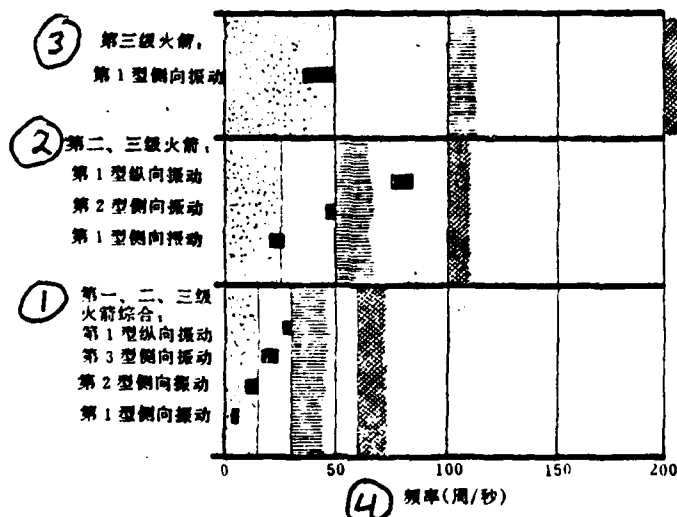


Chart 2-40 Vibration Frequency of a Rocket

1. The first, second and third stages of a rocket are combined. model no. 1 has longitudinal vibration; model no. 3 has lateral vibration; model no. 2 has lateral vibration; model no. 2 has lateral vibration.

2. The second and third stages of a rocket: model no. 2 has longitudinal vibration; model no. 2 has lateral vibration; model no. 1 has lateral vibration.

3. The third stage of a rocket: model no. 1 has lateral vibration.

4. Frequency (cycles/second)

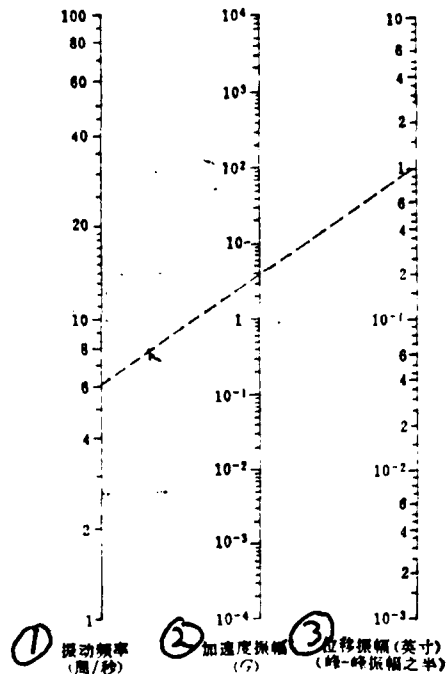


Chart 2-41 The Relation of Sine Vibration Frequency, Acceleration Amplitude and Shift Amplitude

1. Vibration frequency (cycle/second)
2. Acceleration amplitude (G)
3. Shift amplitude (inches) - (half of peak-peak amplitude)

## Section Two Human Body Vibration Transmission

The human body possesses elastic tissues which can be regarded as a elastomer for vibration reactions. The simplest elastomer is the so-called single particle-spring system resembling the one shown in chart 2-41. It includes a particle (mass is  $m$ ), a spring (elastic constant is  $k$ ) and the damping constant is  $C$ . When different human bodies are in a single particle-spring system or in a multi-weight particle-spring system, we can only approximate in using chart 2-42 to describe it.

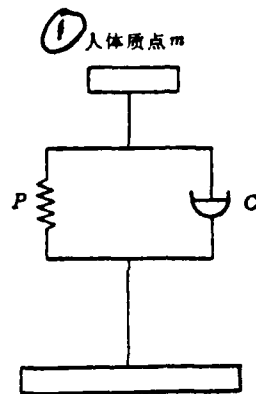
To simplify this, in practice we often use the single particle-spring system shown in chart 2-43 for analogy. This is generally acknowledged but no doubt has its flaws.

Because the human body resembles an elastic system, there is a special relation between the vibration frequency of an object (i.e. a chair) and the transmission of vibration power in the human body and vibration of the human body. Because of this, the active strength of vibration on the human body is not only determined by the strength of the vibration itself but also depends on the body's vibration characteristics and the size of the transmission force of different vibration frequencies in the human body. If vibrations of similar strength are harmonious with the resonant frequency of the human body then their transmission power in the human body will be much stronger than other frequencies. The effects on the human body produced from this will also be stronger. Charts 2-44 to 2-46 separately show the calculated results of vibration transmission of the body in vertical, longitudinal axis and seated postures.

These charts show that when the whole body is vertical and vibration is in 4-8 cycle/second frequency, there is the greatest resonant peak which is called the first resonant peak. The vibrations of this frequency have the greatest transmission in the human body. There are two relatively small resonant peaks in the 10-12 cycles/second and 20-25 cycles/second range and are separately called the second and third resonant peaks. They also have relatively large transmission in the human body.



The first resonant peak is mainly determined by chest measurement resonance and it has the greatest effect on the internal organs in the chest. The second resonant peak is determined by abdominal area internal organ resonance and its effect on the internal organs in the abdominal area is relatively large.



Single particle-spring system

Chart 2-42    Seat or Vibro-Bench

1. Human body particle m

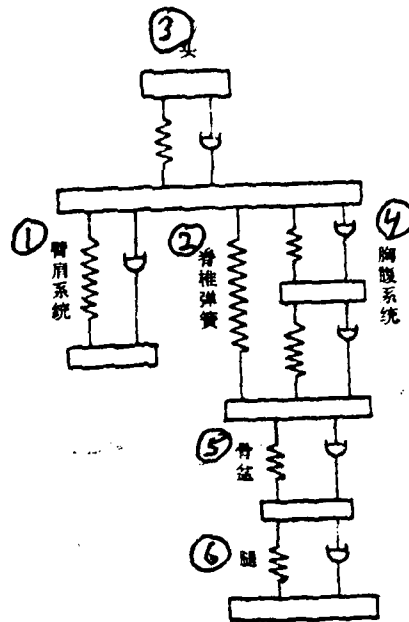


Chart 2-43 Multi-Weight Particle-Spring System

1. Arm and shoulder system
2. Vertebra spring
3. Head
4. Chest and abdominal system
5. Pelvis
6. Leg

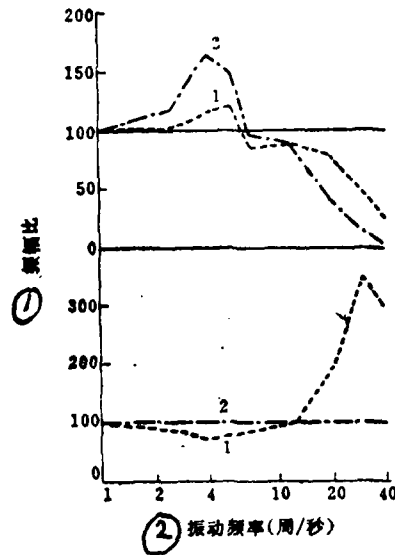


Chart 2-44 The Peak-Peak Shift Amplitude Ratio of the Head (1), Shoulder (2) and Vibro-Bench When Starting Erect (Verticle Vibration)

In the top chart, the shift amplitude of the virbro-bench is 100 and in the bottom chart the shoulder amplitude is 100.

1. Amplitude ratio
2. Vibration frequency (cycles/second)

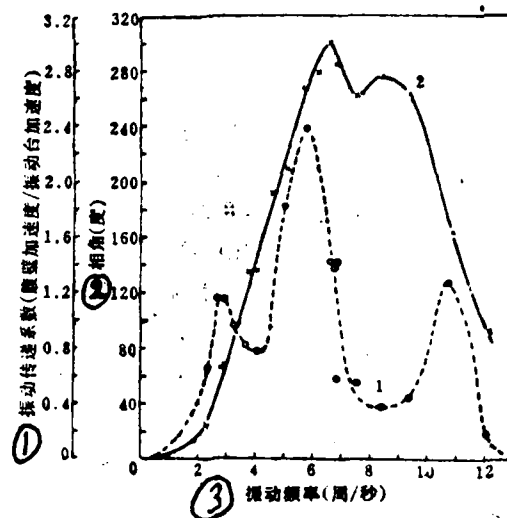


Chart 2-45 The Transmission Coefficient of Human Body Longitudinal Axis Vibrations

Line 1 - Vibration transmission coefficient  
Line 2 - Phase Angle

1. Vibration transmission coefficient (abdominal wall acceleration) (vibro-bench acceleration)
2. Phase angle (degrees)
3. Vibration frequency (cycles/second)

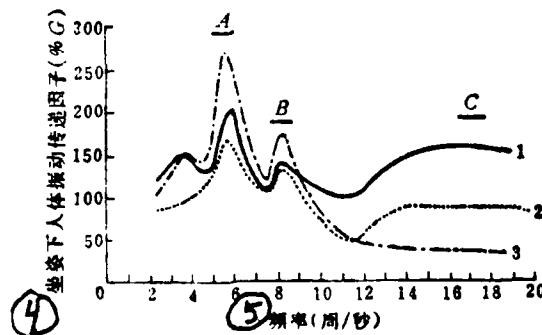


Chart 2-46 Vibration Transmission Factor When in a Seated Posture (Vertical Vibration)

Line 1 - Head-buttocks transmission factor  
Line 2 - Buttocks/seat transmission factor

Key-continued next page

Line 3 - Head/seat transmission factor

A - Chest measurement and chest muscle discomfort

B - Unclear vision and abdominal area discomfort

C - Unclear vision

4. Human body vibration transmission factor when in a seated posture (% G)

5. Frequency (cycles/second)

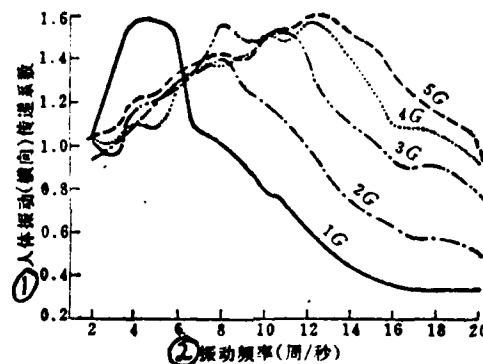


Chart 2-47 Relation of Human Body Vibration (Horizontal) Transmission Coefficient and Overweight Numerical Value

1. Human body vibration (horizontal) transmission coefficient
2. Vibration frequency (cycles/second)

The above represents the situation under normal gravitation on the earth's surface. If gravity is increased then there can be shifts of the human body's resonant peak. Following the increases of overweightness, the resonant peak has a tendency to shift towards a relatively high frequency. Under 5 G positive overweightness, the human body's first resonant peak can shift from 4-8 cycles/second to 12 cycles/second. It can be seen from the curves in chart 2-47 that the greater the overweight numerical value the more the resonant peak frequency shifts towards a

high frequency direction.

When the human body sustains vibrations in different directions, besides vibrations produced in the above mentioned direction, vibrations can also occur in the other directions. For example, when vibrations are sustained by a person in a standing or seated posture, the head can produce elliptical movements which is indicated by the existence of the upper and lower vibration components. This is explained by the simplified recordings in chart 2-48. When low frequency vibrations are below 5 cycles/second, the higher the vibration frequency, the more the head tends to move vertically. When horizontal vibrations are 4-5 cycles/second, head movements seem to become vertical. It can be seen from chart 2-48 that when vibrations are 1 cycle/second, the head basically has horizontal movement. When vibration frequency gradually increases, head vibrations tend more and more towards vertical vibration.

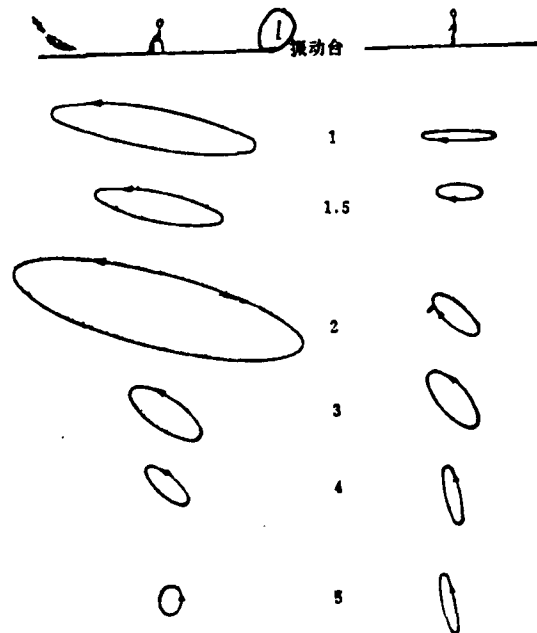


Chart 2-48 Elliptical Vibrations of the Head When There are Horizontal Vibrations

The numbers in the chart are the vibration frequencies (cycles/second)

1. Vibro-bench

The above discusses resonance in the whole body when it is vibrating. Under whole body vibration, there is also local resonance. Resonance frequency of the chest-abdomen internal organs are separated into 4-8 cycles/second and 10-12 cycles/second. The spinal column is 30 cycles/second, resonant frequency of the eyes is 18-50 cycles/second, the head is 2-30 and 500-1,000 cycles/second, the hands are 30-40 cycles/second, the nervous system is 250 cycles/second, the sinus cavity, nose and throat are 1,000-1,500 cycles/second and the resonant frequency of the upper and lower jaw are 6-8 cycles/second.

After vibrations are transmitted by the bones and diffused, sometimes the lever action of the bones causes amplitude enlargement or shrinkage in certain parts of the human body. If low frequency and high high amplitude vibrations are greater than the body's contact area, this can often effect individual organs and the whole body. When there are less than 3 cycles/second frequency and over 0.5 centimeter amplitude vibrations, this can effect the whole body. When the vibration center is in the lumbar vertebra and the body shakes, head shaking is greater than that of the lumbar vertebra. When the vibration contact surface is on the bottom of the feet, in a seated posture, vibration is not transmitted to the torso or when it is, the amplitude is already very small.

### Section Three    Reception and Major Symptoms of Vibrations

#### 1. Local Vibration Feelings

People can only produce vibration feelings when vibrations are 10-1,500 cycles/second. When vibrations are lower than this, a single stabbing feeling is perceived and when vibrations are above 1,000 cycles/second, there is the feeling of continual itching, numbness or stabbing pain. People are most sensitive to vibrations of 200-300 cycles/second which can be felt at only 0.001 micrometer amplitude. More specifically, when vibrations are in the 1,000 cycles/second range a person often feels itchy, at several thousand cycles/second a person feels stabbing or pains and when vibrations are in the 20,000 cycles/second range, under very low strength, there are feelings of softness. Following the



increase of vibration strength there is a burning feeling and supersonic frequency vibration ( $> 900$  kilocycles) feelings often last 10-20 seconds wherein there is mainly a burning feeling. When skin vibrations are in the 50 cycles/second range and strength exceeds 0.1 G, feelings of discomfort begin and when above 0.4 G it is unendurable.

## 2. Vibration Reception in the Whole Body

The feeling threshold of horizontal vibrations in the whole body lies in the 0.00036-0.002 G acceleration amplitude range. The subjective feeling of less than 50 cycles/second sine vibrations in the whole body change according to vibration frequency and amplitude. See details in table 2-18.

① 振动频率 (周/秒)	② 加速度振幅 (G)	③ 主 诉
$<1$	0.1	④ 头内振动感
0.3		⑤ 连续几分钟后, 振动敏感的人有不舒适感觉
0.3	$>1$	⑥ 肌肉痛
1~2		⑦ 长时间作用令人瞌睡
3~4		⑧ 肌肉松弛时有腰、胸、肩部的振动感
5~8		⑨ 不舒适、难受、呼吸和语音被干扰
8		⑩ 身体中心觉得下移, 腰腹部扑动
9~30		⑪ 脸、额、颈部扑动, 视觉干扰
$>20\sim30$		⑫ 不舒适感较低频振幅为轻
$>100$		⑬ 振动强度如果不特别大, 感觉仅限于臀部和其它多肌肉部位, 有时这些部位感到疼痛

Table 2-18 (Key-next page)

Table 2-18 Major Symptoms of Vertical Sine Vibrations in the Whole Body (A Person Sitting Upright in a Hand Chair)

1. Vibration frequency (cycles/second)
2. Acceleration amplitude (G)
3. Chief complaints
4. Vibrating feeling in head
5. After continuing for several minutes, a person sensitive to vibration feels uncomfortable
6. Muscle pains
7. Long time action causes a person to feel drowsy
8. When the muscles relax, there are vibration feelings in the waist, chest and shoulders
9. Discomfort, ill feelings, respiration and speech are disrupted
10. The body center feels like it is shifting downwards and there is waist and abdominal fluttering.
11. Face, cheek and neck fluttering; vision disrupted
12. Uncomfortable feelings, relatively low frequency vibrations are light
13. If vibration strength is not especially great, the feelings are limited to the buttocks and other areas with many muscles. There is sometimes pain in these areas

Aside from these feelings, if there are relatively strong vibrations in the whole body, then there are feelings of discomfort and a series of major symptoms. When vibration strength is not very great, the symptoms are generally discomfort, exhaustion, drowsiness and short attention span. People who are more sensitive to vibrations may face dizziness and headaches. If vibration strength is even stronger and action time longer, this can cause perspiring, difficulty in speech, unclear pronunciation, lack of mental concentration, obstruction to posture balance and impairment in space direction. In serious cases, there can even be ringing in the ears, nose bleeds and buttock and perineum pains. Vibrations that last a long time can cause the human body to become

weak and emaciated. Chart 2-49 demonstrates the chief complaints, feelings and various physiological reactions brought on by vibrations in the whole body. Chart 2-50 shows that when vibration frequency is lower than 10 cycles/second, the major complaints are in the chest-abdominal area; when vibration frequency is greater than 10 cycles/second, then the major complaints are in the head area.

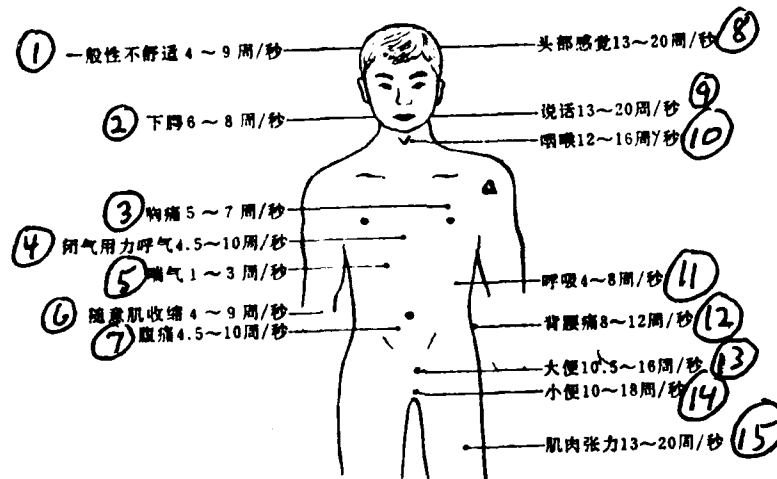


Chart 2-49 Feelings and Symptoms Caused by Different Frequency Sine Vibrations in Different Parts of the Body  
(Limited to Actions in the Endurable Range of 1-20 Cycles/Second Along the Longitudinal Axis of the Body)

1. General discomfort, 4-9 cycles/ second
2. Lower jaw, 6-8 cycles/second
3. Chest pains, 5-7 cycles/second
4. Air is obstructed and so difficulty in exhaling, 4.5 - 10 cycles/second
5. Asthma, 1-3 cycles/second
6. Voluntary muscle contractions, 4-9 cycles/ second
7. Abdominal pains, 4.5-10 cycles/second
8. Head sensations, 13-20 cycles/second
9. Speech, 13-20 cycles/second

10. Pharynx and larynx, 12-16 cycles/speed
11. Respiration, 4-8 cycles/second
12. Back and waist pains, 8-12 cycles/second
13. Defecation, 10.5-16 cycles/second
14. Urination, 10-18 cycles/second
15. Muscle tension, 13-20 cycles/second

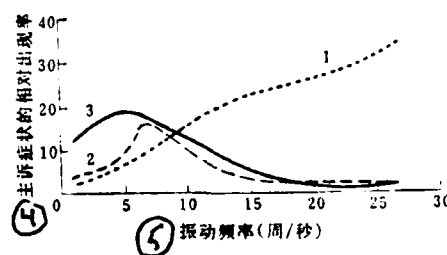


Chart 2-50      Occurrence Rate of Major Complaints in Different Parts of the Body Caused by Different Frequency Vibrations

- Line 1 - Head complaints
- Line 2 - Complaints of the four limbs
- Line 3 - Complaints of the chest and abdominal areas
- 4 - Relative occurrence of chief complaints
- 5 - Vibration frequency (cycles/seconds)

The reason for the major symptoms and feelings are complex and multiple and without a doubt the mechanical effects occupy a dominant position. However, it is a very complex matter to discuss the physiological mechanisms of these effects. We must point out that the human body is an organism and the feelings and complaints arise from the cerebral cortex. The reason the cerebral cortex produces these processes is because the receptors of the peripheral organs and tissues receive vibration stimulation and provide impulses and the impulses are transmitted by the nerves

to the higher center, are synchronized and later produce feelings and major complaints. For example, head discomfort and pain are partially due to shifts and distortions of facial skin and subcutaneous tissue, thus stimulating their receptors, and impulses are sent to the cerebrum. Eyeball resonance occurs at over 50 cycles/second, yet lower frequency vibrations can cause vision impairment. This is possibly related to human body and head area resonance. Further, if upper and lower jaw resonant frequency is 6-8 cycles/second, this vibration can cause vision and speech disruption. The larynx and pharynx seem to feel as if they are being pulled by an object and this causes pain.

Chest pains occur when there are 5-9 cycles/second and they are related to the horizontal movements of the diaphragm. Under these conditions, asthma usually occurs due to shifts of the heart and lungs. Abdominal pains occur at 4-10 cycle/second frequency which is most likely due to the ligaments of the ileum, caecum, transverse colon and liver being elongated. Vibrations in the colon, rectum and bladder often cause a desire to defecate and urinate. When there are vibrations many symptoms such as nausea, vomiting, perspiring, vertigo, trembling of the eyes, posture imbalance and space direction impairment occur. All of these, which belong to the motion sickness category, are mainly due to vibration stimulation of the vestibular organs which causes vestibular autonomic reactions.

From a physiological point of view, we must stress that, aside from the recognized joined and integrative actions of the

peripheral receptors and the central nervous system, we are unable to penetrate the physiological qualities of these surface phenomena. Obviously, peripheral organ reception of vibration stimulation is feeling and is the basic source of major complaints and symptoms.

#### Section Four    Physiological Effects of Vibration

The main effects of vibration on the human body are mechanical effects, a fact which has been repeatedly pointed out in earlier sections. This section will separately describe the physiological effects on each system and each organ. Generally speaking, weak vibrations mainly cause shifts and pressure on tissues and organs which effect their functioning. Strong vibrations cause mechanical injury to organs and tissues, such as impact, pressure and tearing injuries. The human body's reflexive and compensation reactions to vibrations are an important aspect of the physiological effects of vibrations and this will be explained below.

##### 1. The Cardiac Blood Vessel System

The reactions of this system to vibrations are quickening of the heart rate, a rise in blood pressure, an increase in pulse pressure and peripheral blood vessel systolis. Strong vibrations above 50 cycles/second in the whole body can cause blood vessel spasms. These cardiac blood vessel reactions are mostly reflexive and are possibly completed by the sympathetic nerve - adrenal gland system.

## 2. Respiratory System

The most obvious reaction of the respiratory system to vibration is excessive breathing. When the frequency is greater than 4 cycles/second and the amplitude of the whole body vertical vibration is close to 2.5 millimeters, pulmonary breathing noticeably increases. When vibration amplitude is higher than 6 cycles/second, oxygen consumption increases and the respiratory quotient rises. An increase in pulmonary breathing is mainly caused by an increase of moisture volume and the respiratory rate does not rise much. However, in 0.1-1 G vibration, there is very little change in the moisture volume. Increases in pulmonary breathing volume begin to occur when vibration is above 0.3 G and the greatest effect is when vibration is 4-5 cycles/second. If acceleration amplitude is fixed and does not change, oxygen consumption increases because of vibration and reaches its highest peak at 2 cycles/second. Vibration can also cause the arterial carbon dioxide component to decrease. Whether or not the above mentioned respiratory changes cause growth in metabolism brought on by vibrations and this causes respiratory changes cannot be answered at present.

Strong vibrations can cause pulmonary tissue tearing and pulmonary bleeding. The major symptoms are respiratory pains, chest pains, infarction and suffocation. These are naturally the result of mechanical injuries directly sustained by the pulmonary tissues.

## 3. Digestion and Secretion Systems

Strong low frequency vibrations inhibit gastrointestinal

tract peristalsis and digestive juice secretion. This is a type of reflexive reaction and is unquestionably sympathetic nerve excitation, vagus nerve inhibition or the result produced by both of these. The stimulation of these autonomic nerves arises from the impulses of the receptors. Strong vibrations can also mechanically produce gastrointestinal tract injuries which result in gastrointestinal bleeding, abdominal pains, secretion, blood in the stool and gastric juice secretion disorders.

#### 4. Motion Sickness and Hearing

Vibrations in the head stimulate the otolith, especially the lentiform capsule otolith. This induces vestibulo - autonomic nerve reactions and motion sickness. This type of effect is not noticeable when vibrations are 0.1-1 cycle/second. The combination of vibrations and very strong noise can also strengthen occupational deafness and cochlea neuritis.

#### 5. The Musculoskeletal System

Medium strength, relatively long term vibrations, can easily cause head, neck, back and lower limb muscle tension, muscle exhaustion and a decline in motor abilities. Strong and long term vibrations cause muscular atrophy and tension decrease, and sometimes muscular spasms, sciatica, buttock and pudenda pains occur. Vibrations in the trachea and larynx muscles cause speech to be inconvenient and uncomfortable and these muscles to feel swollen. Large vibrations can cause an unsteady posture and produce a grasping defense reflex. Even stronger vibrations



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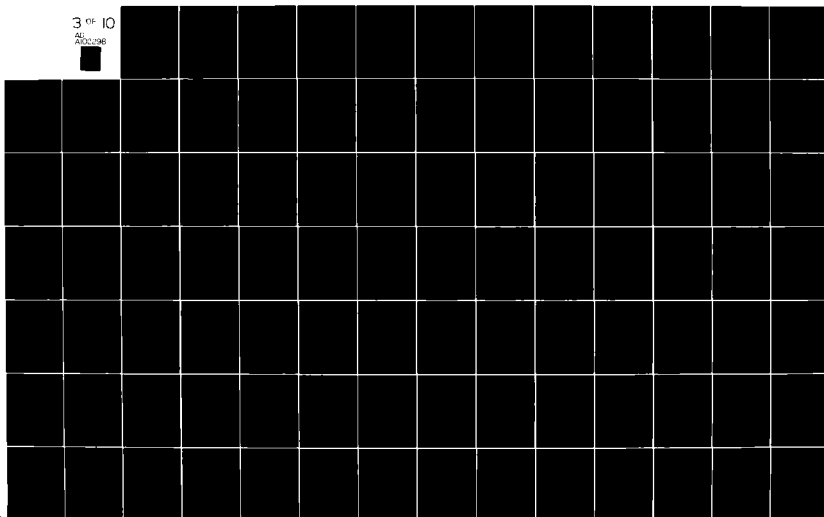
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can cause musculoskeletal system injuries and blood spots.

#### 6. Effects on the Nervous System

The major effects are on energy such as exhaustion and insomnia. Yet, sometimes it can also cause conditional reflex and unconditioned reflex abnormalities. The effect of vibrations on higher nerve activity is mainly inhibition. In the area of direct injuries, strong vibrations can produce morphological changes in the nervous system.

#### 7. Effects on Flight Capability

Vibrations affect vision, speech and operation activities. Among these, the effects on vision are most prominent and sometimes vision can decrease several fold. When there are vibrations, there is an unfavorable effect on firing precision. Other visual work such as instrument reading also becomes inferior. This area is directly affected by vibration and causes the field of vision to tremble and be unsteady and causes inaccuracy in muscle and joint control. On the other hand, there is exhaustion and thus lack of concentration which is a factor which cannot be overlooked.

Vibrations can affect speech quality and cause the voice to shake. When vibration is 6-8 cycles/second, speech comprehensibility is most deficient.

The effect of vibration on operation activities is directly related to shaking in the hands and lack of precision in movements. A decline in operation efficiency is clearly related to acceleration amplitude. The larger the G number, the greater the

decline of operation efficiency.

Table 2-19 and chart 2-51 summarize the physiological effects of vibration on each organ and system.

① 振动频率(周/秒)	② 主 诉 症 状						
③ 腹 痛	④ 胸 痛	⑤ 胃 九 痛	⑥ 头 部 症 状	⑦ 呼 吸 困 难	⑧ 焦 虑	⑨ 一 般 性 不 舒 适	
1				× × × × × × × ×		× × ×	
2				× × × × × × × ×		× × × ×	
3	× ×	× ×		× × × × ×	×	× × × × ×	
4	× ×	× ×		× ×	× × ×	× ×	× × × × ×
5		× × × ×				×	× × × × × ×
6	× × ×	× × × ×		×			× × × ×
7	× ×	× × × × ×	×	×			×
8	×	× × × ×		×		× ×	× × ×
9	× ×	× × × ×			×		× × × × ×
10	×	×	× × ×	× ×		×	
15							× × × × × × × ×

Table 2-19 Major Complaints Under Different Vibration Frequencies.

1. Vibration frequency (cycles/second)
2. Major complaints and symptoms
3. Abdominal pains
4. Chest pains
5. Orchiodynia
6. Head symptoms
7. Respiration difficulty
8. Anxiety
9. General discomfort

Note: in the chart, the more "x" marks that are indicated, the higher the occurrence rate

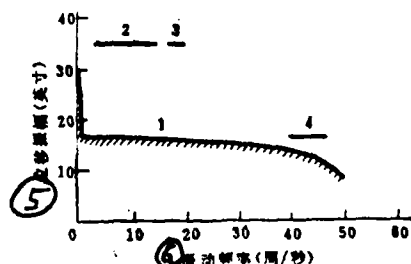


Chart 2-51 Curve of Human Safety Limit to Vibration

- Line 1. Safety limit
- Line 2. Anterior cardiac area
- Line 3. Nausea, abdominal tic and blood in stool
- Line 4. Instrument reading difficult
- 5. Shift of amplitude (inches)
- 6. Vibration frequency (cycles/second)

#### Section Five Endurance to Vibration

There are generally two criteria for measuring a person's endurance to vibration. The first begins when there are feelings of discomfort and is called the discomfort threshold. The second is demarcated by feelings of non-endurance and is called the major endurance limit.

The major endurance limit of the whole body to vibration is related to exposure time to vibration. For a comparison of vibration for a short period of time (the strength continually increases according to a 0.75 millimeter peak-peak amplitude/second growth rate and suddenly stops at the major endurance limit) and vibration for a long period of time (1-3 minutes) see chart 2-52. It can be seen from this chart that the three endurance limit values are different and the lowest is 3 minutes.

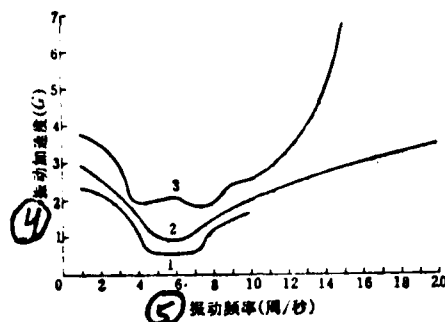


Chart 2-52 Whole Body Sine Endurance Curve (Indicated by Acceleration)

- Line 1. 3 minute endurance limit
- Line 2. 1 minute endurance limit
- Line 3. Short time (shorter than 1 minute) endurance limit
- 4. Vibration acceleration (G)
- 5. Vibration frequency (cycles/second)

In summary, a person's lowest endurance to vibration is within 4-8 cycles/second. This frequency is the human body's resonant frequency and it has a great physiological effect on the human body.

The question of the vibration discomfort threshold of the whole body can be summed up as follows: vibration below 20 cycles/second and acceleration amplitude above 0.01 G can call people's attention and when over 0.048-0.05 G, this can cause people to be unhappy.

The major endurance limit of vibration in the whole body when one is doing physical labor can be summarized as follows:

- (1) When acceleration amplitude value is 6-20 cycles/second, the vibrations in the whole body do not exceed 0.33 G;

(2) when the peak-peak amplitude decrease rate is 20-60 cycles/second, it does not exceed 2.6 millimeters/second.

## Section Six    Protection Against Vibration

### 1. Anti-Vibration Elastic Cushion

This is a protective measure against vibration commonly used in aircraft and spaceships. A well designed elastic cushion can cause vibration in an aircraft and spaceship to weaken so that very little vibration is transmitted to the human body. However, if there is only vibration protection to the human body and vibration protection is neglected for instruments and controllers, then a contradiction occurs between the relative static of the human body and the relative vibration of the instruments and controllers and as a result there can be a decline in operation efficiency. This is a problem which must be given attention to in technical design.

### (2) Binding Strap System

One of the most important effects of vibration is the shifts of internal organs in the chest-abdominal area and because of this chest-abdominal pains and respiration difficulty occur. Therefore, the design of a binding strap system must focus on limiting the shifts of internal organs in the chest-abdominal area. At the same time, it is necessary to consider the problems of anti-overweightness and anti-impact and to make unified, rational and universal binding strap equipment.

### (3) Suitable Postures

Vibration transmission is different when the human body is

in different postures. Because of this, in work, it is necessary to select suitable postures to decrease the effect of vibration. To complete this point, reliance on a single voluntary control is difficult and can easily lead to exhaustion. It is best to use a chair with a suitable sitting posture.

#### (4) Training

Repeated vibrations which can cause a person to feel discomfort, autonomic nerve obstruction and negative effects on the central nervous system mechanism can be gradually lightened or eliminated. Yet, one must pay attention to see that training is not excessive; otherwise it can be harmful to the health. Because the actual effects of training against vibrations are not very great and it is easy to use supplementary actions, many people do not agree on its use.

#### (5) The Adoption of Aircraft Technical Designs and Technical Measures to Decrease Vibration Causes it to be Below Safety Standards

These are the most positive and important measures of protection against vibration. However, the specific design, development and installation of anti-vibration measures belong to the area of engineering technology which this book does not deal with in detail. Vibration safety standard data is provided below for reference. When vibration frequency is greater than 1 cycles/second amplitude should not exceed 0.6 millimeters; when vibration is 1-3 cycles/second, each frequency increase of 1 cycle/second allows the amplitude to decrease 0.2 millimeters; vibrations of 4 cycles/second allow the amplitude to be 0.1 millimeters; vibrations of 5-7 cycles/second allow the amplitude to be 0.07-1.0 millimeters;

vibrations of 8 cycles/second are 0.05 millimeters; each increase of 1 cycle/second in later frequencies allows the amplitude mean to decrease 0.005 millimeters and vibrations about 11 cycles/second allow the vibration speed to be 0.22-0.27 centimeters/second. Spaceships very rarely receive high frequency vibrations and therefore their safety standards are not given.

#### Section Seven Trembling

In recent years, for low air attacks and reconnaissance needed in military affairs, aircraft were required to carry out low altitude (under 300 meters), high speed flights, sometimes flight altitude was only 30 meters or less. In future spaceships, to carry out high speed photography and examination of celestial body surfaces, it will also be possible to carry out flights similar to this. An important feature of low altitude, high speed flight is that air resistance is great, there is a lot of earth surface dirt, the aircraft moves up and down following the unevenness of the earth's surface and thus causes shock vibration. This type of vibration is called trembling. The biophysical definition of trembling is the combination of single vibrations when head acceleration is greater than 0.1 G. Chart 2-53 is the trembling recorded in an aircraft and is an imagized case in point.



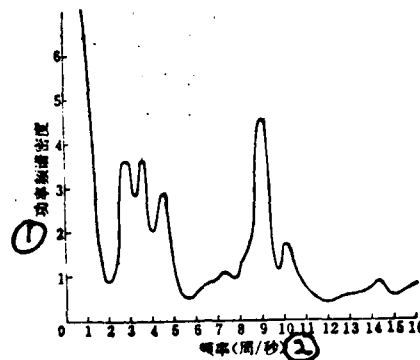


Chart 2-53 One Example of a Power Frequency Spectrum Density of Severe Trembling in Low Altitude, High Speed Flight - Pilots Complain of "Severe Turbulence"

1. Power frequency spectrum density
2. Frequency (cycles/second)

Tests carried out on aircraft have shown that trembling in low altitude, high speed flight mainly occur in the up and down directions and very rarely in level flight. Under these types of flying conditions, a pilot's heart rate increases 16-36 times/minute and his respiration rate increases 10-15 times/minute. The chief complaints by pilots are difficulties in map and instrument reading and in writing. Because of this, they can only raise their eyes to sight ground targets when in flight. There were also difficulties in operating the switches. When there was trembling, they felt discomfort and vexation. Individual pilots sustained severe head pains when there was trembling due to their heads colliding with the cockpit cover. At the same time, they suffered shoulder pains when the trembling caused shoulder strap pressure to increase.

The physiological effects of trembling on the human body are closely related to trembling frequency. Trembling at 1-20 cycles/second has a great physiological effect on the human body and is about 15 times greater than trembling at  $<0.2$  and  $>100$  cycles/second. This is possibly related to human body resonance.

When there is trembling, a person's operating abilities and signal monitoring efficiency are noticeably decreased and when the G number increases, these types of effects increase. Sometimes these types of effects continue for a specific time after trembling stops and then disappear. Table 2-20 lists the major complaints and major endurance limits to trembling. It can be seen from the table that the mean square G value of the trembling determines the essential objective factor of these two numerical values. Naturally, this does not remove the effects of other physical and physiological factors.

① 按设备计算所得的震幅均方根 $G_z$ 值 ( $G_z$ )	② 试验内实测所得的震幅均方根 $G_z$ 值 ( $G_z$ )	③ 可耐时间	④ 主 诉 症 状
0	0~2	⑤ 几小时	⑥ 舒适, 只感到操纵科目所造成的负荷
0.15	0~2.5	⑦ 几小时	⑧ 无不适感, 轻度干扰气流
	0.1~0.2 (1~12周/秒)	⑨ > 3小时	⑩ 无不适反应
	>0.3	⑪ 几小时	⑫ 长时间后有不适反应
	0.11	⑬ 4小时	⑭ 主诉可耐限
0.35	-1.2~4.0	⑮ > 30分	⑯ 感到很严重的干扰气流、疲劳
0.50	-2.5~5.0	⑰ 5分	⑱ 一次飞行中这种震幅不宜超过一回
	1.6~2.5	⑲ 5分	⑳ 恶心和不适反应
0.70	-3~5.5	㉑ 100秒	㉒ 主诉可耐限
	4~5	㉓ 5~15秒	㉔ 黑视或视觉模糊等症状

25 ● 正值与负均重, 负值为负重量。均方根  $G$  值是拟将每一时刻上的震幅重量数值 ( $G$  值) 平方以后进行平均, 然后开平方所得的数值。

Table 2-20 (Key next page)

Table 2-20

A Person's Reception of and Major Endurance Limit  
to Vertical Trembling

1. Trembling mean square  $G_z$  value ( $G_z$ ) calculated from the equipment
2. Trembling mean square  $G_z$  value ( $G_z$ ) measured in the cockpit
3. Endurance time
4. Major complaints
5. Several hours
6. Several hours
7. > 3 hours
8. Several hours
9. 4 hours
10. > 30 minutes
11. 5 minutes
12. 5 minutes
13. 100 seconds
14. 5-15 seconds
15. Comfortable, only felt load created by operating item
16. No uncomfortable feelings, light disturbing airflow
17. No uncomfortable reactions
18. There were uncomfortable reactions after a long time
19. Major endurance limit
20. Felt very severe disturbing air flow, exhaustion
21. This type of trembling did not occur more than once in each flight
22. Nausea and uncomfortable reactions
23. Major endurance limit
24. Blackened or blurry vision
25. [Note] Positive values are positive overweightness and negative values are negative overweightness. The mean square G value indicates the mean derived after each trembling overweight numerical value (G value) is squared and then the numerical value is derived from the extraction of the root

## CHAPTER SEVEN

### THE EFFECTS OF ROTATION AND OSCILLATION - AERIAL SICKNESS

#### Section One    Rotation and Loops

In both aircraft and spaceships there is the possibility of sustaining various different axial rotations. In physical terms, rotation is angular speed motion and angular acceleration motion. When an aircraft makes a tight turn, spirals, rolls, loops etc. as well as when a person is ejected out of the cabin, due to airflow swaying different levels of rotational motion can be produced. Under weightlessness, when a spaceship's attitude control system is not good, any minute force can cause the spaceship to float and vibrate. If the force is excessively large on one side, this can cause the ship to turn to the side. This type of turning is possible to the left, right, up and down and when the turning is very violent it can form rotation. The production of rotation by a spaceship in flight is very common. Aside from this, when an astronaut leaves the cabin and moves in outer space, if he only uses a safety rope for binding, as soon as each part of his body uses force unevenly he cannot avoid having his body rotate or roll. When using a jet gun to help change direction and move about, because the jet force and its action direction control are improper, rotation, rolling and somersaults can be produced on each axis line. When a person

lives in a rotating artificial gravity space station, all day he dwells in a rotating environment. Generally, the effect of rotation on the human body in a spaceship is a problem of actual existence.

#### I. Rotation and Gravitational Receptors

It is difficult for the human body to directly feel rotation when the large radius is steady. The earth itself is continually rotating and also revolving around the sun but people living on the earth do not feel the earth's revolving nor the continual turning of the earth. If we try placing a person in a continuously rotating room, after a certain amount of time they will still not feel the rotation. In reality, people directly feel rotation (not seeking aid from sight, hearing and touch) mainly because of angular acceleration and not because of angular speed of the body. Thus, when rotation begins or the moment rotation stops, as well as when rotation changes, people can feel it. Why is this? This is because a person's feeling of rotation is governed by a receptor located in the inner ear called the labyrinth receptor. The labyrinth receptor only reacts to angular acceleration.

Chart 2-54 shows the position of the labyrinth receptor in the head and its shape with the otolith and cochlea hearing organs.

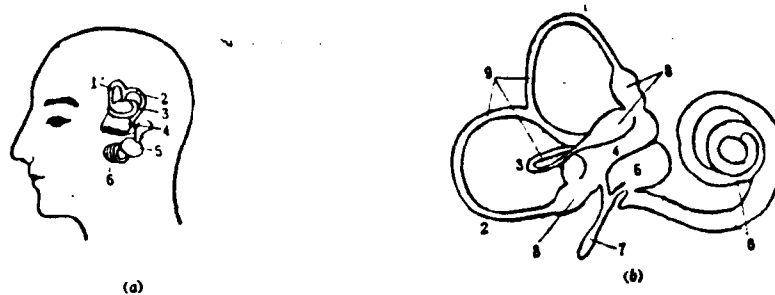


Chart 2-54    The Labyrinth Receptor

a. Normal position of the inner ear on the left side of the head

1. Interior semi-circular canal
2. Posterior canal
3. External canal (horizontal canal)
4. Utricle
5. Lenticular sac
6. Cochlea canal
7. Endolymphatic tube
8. Ampulla
9. Three semi-circular canals

b. An enlargement of chart a (the position seen from the the front side)

This chart shows that the labyrinth organ is composed of three semi-circular canals. Among them, one lies on the outside horizontal position and is called the external canal. The other two lie on the inside and both are vertical to the ground; one is a bit higher and is called the anterior canal; the other is a bit lower and is called the posterior canal. They form a right angle with each other. The inside of the semi-circular canals is filled with lymphatic fluid. The center of each semi-circular canal has an expanded area called the ampulla and the ampulla of

each canal has a receptive unit called the "auditory ridge". These terms are taken from the structural mechanisms of lower animals and among the higher animals which includes man - the auditory ridges have no hearing functions. They are the angular acceleration receptors. The auditory ridge ciliated cells are clustered together and are covered by a cap-shaped colloid. The whole structure seems to be in an upside down clock cover.

Chart 2-55 shows the microstructure of an auditory ridge.

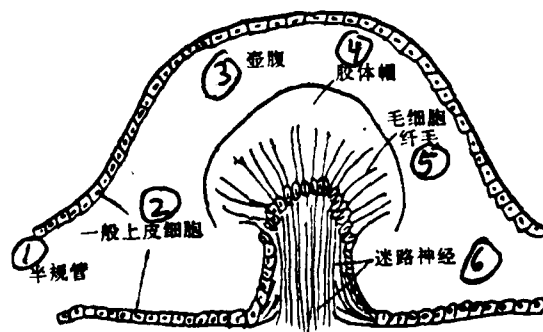


Chart 2-55 Schematic Diagram of a Semi-Circular Canal Ampulla's Auditory Ridge Hair Cells and Colloid Cap Structure

1. Semi-circular canal
2. Common epithelial cells
3. Ampulla
4. Colloid cap
5. Hair cell cilia
6. Labyrinth nerves

The Colloid cap and hair cell fibers on the auditory ridge do not shift or change shape because of rectilinear acceleration. Yet, each time angular acceleration is sustained by the head or whole body, the endolymphatic fluid in the membranous canal flows causing the colloid cap and fibers to shift. After angular

speed is steady and unchanging, the colloid cap and cilia gradually return to their original positions and do not again produce any stimulation action. The labyrinth receptor can only react to angular acceleration and cannot arouse a receptive mechanism to angular speed. Each semi-circular receptor sustains angular acceleration stimulation from different directions and at the same time causes the reflex reactions of eye shaking and head trembling in different directions.

Besides causing the feeling of rotation, angular acceleration can also produce gravitational changes. The centrifugal force when in rotation can also cause overweightness. Therefore, rotation often simultaneously causes illusions in posture balance and space direction. Below we will briefly introduce the human gravitational receptor.

There are two main types of human body gravitational receptors. One type is called the body receptor and is mainly distributed in the human body's skin, muscles and internal organs. When gravity causes muscle load pulling and shifts and change of shape in the skin and internal organs, these receptors are pressure distorted and send "afferent nerve impulse" signals to the cerebrum. The body receptors are composed of two large systems:

- (1) skin, subcutaneous and internal organ gravity and contiguous receptors;
- (2) muscle, tendon, joint expansion and tension receptors

The other type of gravity receptor is called the special type gravity receptor which is the vestibular otolith. The utricle and lenticular sac make up the vestibular otolith. The



fixed position of the utricle and lenticular sac have special structures being composed of several layers of cells. There are two types of cells: one is the supporting cells and one is a special type of epidermic cell. The latter have minute cilia on them and are called ciliated cells and are the receptors of sense mechanical stimulations. The cilia of the ciliated cells extend into the cavity. There is a layer of colloid covering the surface and periphery of the cilia. The eighth vestibule tips of the cerebral nerves stop in the ciliated cells.

The places where the ciliated cells gather in the utricle and lentiform sac are called acoustic spots (which are not related to the sense of hearing). When the head is in a vertical posture, the position of the utricle acoustic spots is on a longitudinal plane and when the lenticular sacs lie on a vertical surface they are forward and downward. There are many calcium carbonate particles on the cilia called otoliths. The proportion of otoliths is greater than endolymphs and thus shift according to the direction and size of the inertial force or gravitational force. When the head is slanted, they then shift in the direction of the slant. Otolith shifts force the cilia of the ciliated cells to change shape. This type of mechanical stimulation excites the vestibular nerve endings around the ciliated cells to produce impulses and when the information is transmitted to the brain stem center, this can cause various reflexes in regulating posture. When transmitted to the cerebrum, after analysis, the information causes various voluntary regulation actions in the perception and recognition of the head position. Changes in head position cause changes in angular

acceleration and gravity. Therefore, the otoliths which sense this type of change are called special gravity receptors.

The microstructure of an otolith is shown in chart 2-56 and the chart indicates that there are many calcium carbonate crystals on the surface of the sensory cell cilia bundle in the colloid.

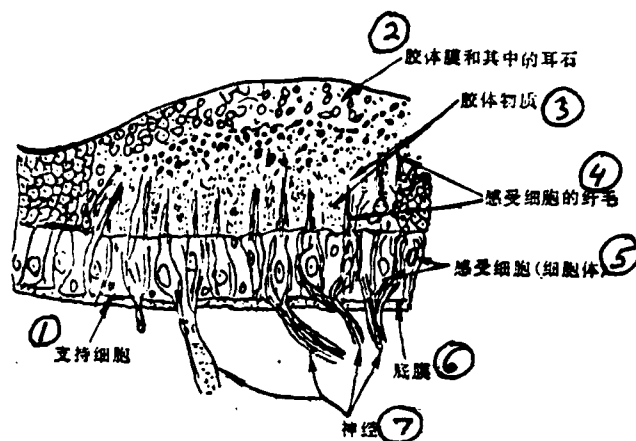


Chart 2-56      Microstructure of an Otolith

1. Supporting cells
2. Colloidal membrane and otoliths in it
3. Colloidal matter
4. Sensory cell cilia
5. Sensory cells (cell bodies)
6. Bottom membrane
7. Nerves

Chart 2-57 shows the action mechanism of the Otolith.

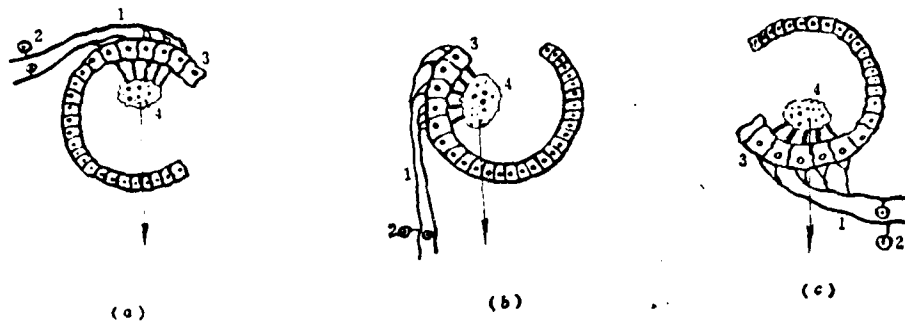


Chart 2-57    The Effect of Head Position on the Otolith

1. Auditory nerve labyrinth supporting fibers
2. Neuromere cells
3. Epithelial cells
4. Otolith (composed of calcium carbonate crystals and colloidal fluid; the arrows indicate the direction of the earth's gravity)
- a. The otolith pulls the hair cell cilia straight down
- b. Pressing the cilia towards the side
- c. Pressing the cilia down (because the directions of pulling and pressing of the hair cell cilia are different which causes feelings and reactions of the head in different positions)

Whatever position the otolith is in, it can pressure distort the cilia. However, the moment the position is stable, it loses the effect of stimulation due to the adaptation of the sensory cells. Adaptation is a universal law of all receptors but adaptation times differ greatly according to the various receptors. When stimulation strength changes or the stimulation position shifts, adaptation is immediately lost. This explains the reason why after the head is fixed in a certain position, the ciliated

cells cannot be excited again and it also accounts for why, when in a vertical posture and the otoliths are in the cilia, stimulation is relatively weaker (in life, more time in the vertical position is taken). When the head inclines forward or backwards or slants or oscillates to the left or right, the power of the otoliths to pull and distort the cilia is relatively strong. In the latter question, mechanical factors and physiological factors (sense organ adaptation) are possibly activated.

## II. Illusions of Rotation and Threshold Acceleration

There are two main effects of rotation on the human body. The first is the production of illusions in space direction and the second is the production of motion sickness. Section three in the latter part of this chapter will discuss the question of motion sickness but here we will first write on illusions in space direction caused by rotation. There are two types of illusions in space direction:

1. When rotation begins and finishes, angular acceleration stimulates the semi-circular canal which causes people to feel that there is rotation. At the same time, the auditory ridge in the semi-secular canal sustains angular acceleration and after shifting produces elastic reduction. In the reduction process there is also some vacillation. Because of this, there is a series of illusions produced during this process. For example, not long after rotation begins, there is sometimes the feeling of turning in the reverse direction. This type of illusion is called the reverse rotation illusion. Not long after rotation stops, there is first the feeling

of turning in the reverse direction and later there is the feeling of turning in the positive direction and this is repeated 4-5 times. This type of illusion is called the post-rotation illusion. The reaction which accompanies these illusions is reflexive eye quivering which causes visual illusions of rotation and reverse rotation and intensifies the above mentioned illusions. This is one of the main reasons for rotation and reverse rotation illusions by pilots and it has an obvious negative effect on air direction and flight operation.

Besides illusions in space direction, rotation sensations and illusions can also cause a lowering of operation capability.

## 2. Illusions in Threshold Acceleration

On the course of rotation, if the body (especially the head) undergoes linear or angular motion, for example, lifting the head to look out of the cabin or lowering the head to read instruments, threshold acceleration reactions can occur. Threshold acceleration is a major cause of motion sickness. Aside from causing motion sickness, threshold acceleration can also stimulate the vestibula otoliths and because they produce abnormal signals various illusions are induced, the body suddenly feels as if it is tumbling, in a somersault or falling. These illusions are one reason why pilots produce flight illusions in the air. They not only affect space direction but can also negatively affect flight operation. Based on results determined in a laboratory, the threshold value produced by a threshold reaction was  $0.06 \text{ radian}^2/\text{second}^2$  and the threshold value produced by a nausea reaction was  $0.6 \text{ radian}^2/\text{second}^2$ . When high speed rotation caused the head to move  $90^\circ$ ,

the threshold value produced by the threshold reaction had a rotational speed of 2.4 cycles/minute. When there was a slow 20°-40° movement of the head when the subject was lying on his back in a ground training aircraft, the threshold value of the threshold reaction was 6.0 cycles/minute. In normal motion, the body and head produce a relatively evident threshold reaction body rotational speed which generally lies in the range of 2 cycles/minute (0.21 radian/second). It can be seen from this that in order to eliminate threshold reactions, when the aircraft rotates, turning of the head should be avoided as much as possible.

## Section Two    The Danger of High Speed Rotation and Somersaults

When a person ejects from an aircraft or spaceship in high speed flight, this very possibly produces high speed rotation or somersaulting of the body. A somersault indicates that the body's lateral axis is the turning of a turning axis or other axis direction. This is because when ejecting, the strength of the head to the shock of tremendous airflow and the aerodynamic actions in each direction are different. At this time, rotational speed can reach 60-180 cycles/minute. It generally begins 0.1 seconds after ejection from the aircraft and rotational speed reaches its greatest value 0.5-1.2 seconds after ejection. Such fast rotation can cause injury to the human body.

The main effects of high speed rotation and somersaults on the human body are caused by the simultaneous action of directional and reverse overweightness (centrifugal force) on the relative position of the human body. The vestibular vegetative reaction

produced from this is a negative effect which is difficult to inhibit. For example, when the heart is taken as the turning center, the upper half of the body sustains negative overweightness and the bottom half of the body sustains positive overweightness. There is a series of symptoms produced from this. The main symptoms are rise of heart rate and respiration rate, drop of pulse pressure, bleeding of eyeball and retina, pains and oozing of blood in the head area, internal organ shifts and difficulty in swallowing. At this time, the eye level hydrostatic pressure is 95 millimeters on the mercury column and foot level hydrostatic pressure is 540 millimeters on the mercury column which causes blood to leave the heart and to fill the peripheral blood vessels of the head, four limbs and abdominal area. As a result, the arteriovenous pressure difference becomes smaller, pulse pressure drops, there is skin color cyanosis, heart output drops and the heart rate quickens.

If the spines of ilium are taken as the turning center, the main symptoms are lowering of the heart rate and respiration rate and the other symptoms are similar to when the heart is taken as the turning center. Here, however, they appear earlier and are more severe. One of the serious physiological effects of high speed somersaults on the human body is circulation collapse which is mainly due to the hydrostatic pressure changes in the head and legs.

If the buttock area is taken as the turning center, then heart output decreases and carotid artery pressure rises which causes the heart rate to slow down and the peripheral blood vessels to fill with blood and become heavy. Because of this, heart

output drops even more but carotid artery blood volume does not decrease and thus the severity of circulation collapse is relatively light. When the buttock area is the turning center, the character of cerebral injuries is similar to those suffered under negative overweightness, the retina, oral cavity mucosa and nose bleed and sometimes purple spots appear on the feet and back. If rotational speed is slow and steady, a person can maintain consciousness and work ability is not completely destroyed. However, when rotational speed suddenly changes, this can possibly cause vertigo and loss of consciousness. If the head is the turning center, the cerebral injuries easily occur.

See table 2-21 for man's endurance to somersaults and rotation. The danger of high speed somersaults can be seen from this table.



① 转心	② 转速(周/分)	③ 到达眩晕的时间(秒)	④ 症 状
⑤ 心	40	—	⑦ 在 2 G 的超重下未见眩晕
	45	600	⑧ 主诉可耐限
	60	0~350	⑨ 眼出血(120~150秒开始)
	75~80	120	⑩ 眼结合膜出血
	80	100	⑪ 眼出血、足麻木
	90●	12	⑫ 主诉可耐限、恶心、呕吐、空间定向障碍
	100	60	⑬ 眼出血(10~15秒开始),前额负超重4~5G
	106	60	⑭ 颈动脉窦和主动脉弓血压降低,下肢静脉压升高
	115~120	3	⑮ 眼结合膜出血
	120	34	⑯ 相似于负超重6~9G,疼痛和弥漫性头痛
	125	2~3	⑰ 主诉可耐限
	140	3~10	⑱ 预计前额负超重9~10G
⑥ 臀	160	3~10	⑲ 主诉可耐限
	160	⑳ 几分钟	㉑ 意识丧失
	25~30	—	㉒ 眼结合膜出血
	50	120~150	㉓ 眼出血(120秒开始)
	60	60~70	㉔ 主诉可耐限
	70	10~15	㉕ 头部压力、不舒适
⑦ 部	80	4~5	㉖ 主诉可耐限
	80~90	3	㉗ 头部压力、不舒适。接近不可耐
	125	—	㉘ 转速稳定下意识良好,转速突变时眩晕

⑳ ● 相当于以800公里/小时的速度弹射。  
㉙ 注:本表每一横行取自一个材料,彼此间可能有不尽相合之处。

Table 2-21 A Person's Ability to Adapt to Somersaults

1. Turning center
2. Rotational speed (cycles/minute)
3. The time vertigo is reached (seconds)
4. Symptoms
5. Heart
6. Buttock area
7. Under 2 G overweightness, vertigo does not appear
8. Major endurance limit
9. Eye hemorrhaging (begins after 120-150 seconds)
10. Retina hemorrhaging
11. Eye hemorrhaging, feet numb
12. Major endurance limit, nausea, vomiting, space direction impairment
13. Eye hemorrhaging (begins after 10-15 seconds), 4-5 G negative overweightness on forehead
14. Carotid artery sinus and arch of aorta blood pressure decrease, lower limb venous pressure rises

15. Retina hemorrhaging threshold
16. Similar to 6-9 G negative overweightness, pain and spreading pains
17. Major endurance limit
18. Estimated 9-10 G overweightness on forehead
19. Major endurance limit
20. Loss of consciousness
21. Retina hemorrhaging
22. Eye hemorrhaging (begins after 120 seconds)
23. Major endurance limit
24. Pressure on head, discomfort
25. Major endurance limit
26. Pressure on head, discomfort, approaching non-endurance
27. When rotational speed is steady, consciousness good and rotational speed suddenly changes, there is vertigo
28. Several minutes
29. Equal to ejection at a speed of 800 kilometers/hour
30. Note: each horizontal line in this table is cited from one source and there are possibly places which do not agree

To prevent somersaults when ejecting or free falling a small stable parachute can be added on to the ejection seat or when free falling and if the stable parachute works normally, somersaults can be greatly decreased or even completely eliminated.

### Section Three    The Effects of Oscillation

Oscillation indicates the swaying back and forth of each axis line on the human body. There are many forms, some resemble the swaying of a pendulum, some resemble the left and right and back and forth turning of a compass and some resemble the swaying of a tumbler. The special characteristic of vibration is its linear back and forth motion and the special characteristic of oscillation is its back and forth angular motion. Both aircraft and spaceships can have oscillation. The oscillation which a

Mercury model spaceship undergoes when returning is shown in chart 2-58.

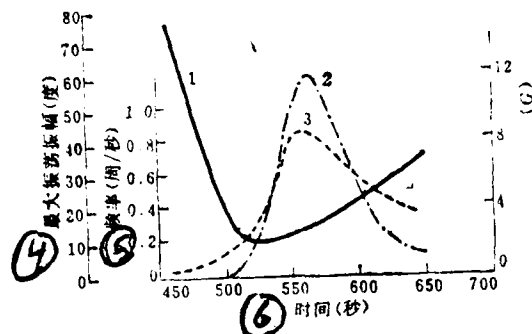


Chart 2-58 Oscillation Curve of a Mercury Model Spaceship During Return

- Line 1. Amplitude
- Line 2. Acceleration
- Line 3. Frequency
- 4. Largest oscillation amplitude (degrees)
- 5. Frequency (cycles/second)
- 6. Time (seconds)

The measured results of the human body's endurance to rolling oscillation in an aircraft are shown in chart 2-59.

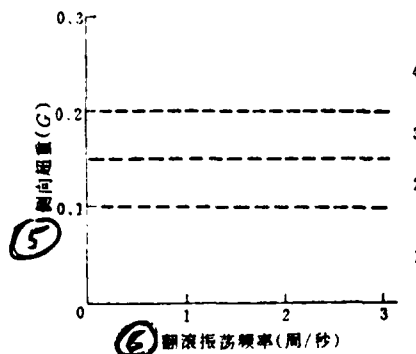


Chart 2-59 Man's Endurance to Rolling Oscillation

1. Permissible area
2. Still permissible area
3. Permissible area for short time exposure
4. Non-permissible area when a spaceship enters
5. Lateral overweightness
6. Rolling oscillation frequency (cycles/second)

Oscillation can be perceived but there is a time difference (phase difference) between real oscillation and human body perception. Because oscillation has unpatterned, multidirectional repeated turns, it therefore violently and repeatedly stimulates the inner ear vestibular organ and causes vestibular vegetative nerve reactions which result in symptoms of motion sickness.

Endurance to oscillation and motion sickness have a cause and effect relationship: oscillation is the cause and motion sickness is the effect. A very large degree of endurance to oscillation limits motion sickness.

When there is pitching and left and right oblique oscillation, the heart rate changes according to the oscillating period; when the G number increases, the heart rate is relatively high; when the G number decreases, the heart rate is relatively low. The higher the oscillation frequency, the smaller the increases and decreases in fluctuations of the heart rate during oscillation.

The tracking control errors during left and right turning oscillation and pitching oscillation change according to the periodic changes of oscillation angular speed. When angular speed increases, errors increase and then decrease. Left and right turn oscillation is similar to pitching oscillation. The raising of instrument illumination can decrease these types of errors.

Because oscillation has a negative effect on the human body and also obstructs flight control and space direction ability, aircraft and spaceships must decrease or avoid oscillation through technological means and at the least lower oscillation strength to a level of human endurance.

#### Section Four      Aerial Sickness (Aerial Motion Sickness)

##### I. Aerial Sickness and Other Major Symptoms

Aerial sickness, also called airsickness, is a relatively common type of illness that occurs in aviation. Its symptoms and mechanisms are the same as those of carsickness and seasickness and medically they are jointly called motion sickness. They

are called motion sickness because this type of illness mainly occurs during motions of cars, boats or aircraft. Motion sickness is often the result of the simultaneous and repeated actions of speed changes, various directional acceleration and angular acceleration. Thus, there is no denying the fact that in certain situations, the vigor of certain individuals affects motion sickness.

After a pilot produces aerial sickness, this will naturally seriously affect flight and fighting capabilities and even cause operation errors and aerial incapacity. It also threatens flight safety but if appropriate protective measures were to be taken beforehand, aerial sickness can be prevented or overcome. Although pilots easily produce flight illusions after having vertigo, yet there are differences in the principles in the qualities and mechanisms of aerial sickness and flight illusions. There are great individual discrepancies in the incidence of aerial sickness, that is, it does not basically occur in some people while a percentage of others often find it difficult to continue flight because of aerial sickness.

The major symptoms of aerial sickness are not completely the same because the patients' conditions are different, there are great individual differences, the lengths of time are different and the places are different. The most commonly seen (yet not everyone has airsickness each time) symptoms are head swelling, headaches, dizziness, vertigo, nausea, paleness, perspiring, salivating, exhaustion, trembling of the eyes and

hands, yawning, chest tightness and aversion to food. In more serious cases, there can also be center symptoms such as confusion and double vision as well as the respiratory symptoms of asthma and choking. When classical aerial sickness begins, a person feels discomfort, that the head is swollen and heavy and slight nausea. However, when lying down the person feels better. If the patient's condition continues to develop, then nausea will be heavier, there will be dizziness, heat and swelling in the head, the whole body will feel weak and the patient will begin to perspire. If the patient's condition further develops, then he will often feel dizzy, unsteady when standing, depressed and even feel like vomiting. After vomiting, the patient will feel more comfortable. Some people only vomit once but only fully recover several minutes to 1-2 hours after the aircraft lands. Because there are often emergency tasks while flying, pilots must have a high and concentrated attention span so that they can immediately inhibit aerial sickness and complete their tasks and then after landing they can have aerial sickness. There are also some people who do not have any preliminary symptoms but suddenly become nauseous and vomit, and there are also those who become nauseous but do not vomit. If the vomit goes into the helmet or face guard, this can block the respiratory tract which is very dangerous. However, this rarely happens because on the one hand, the pilot's positive political sense of responsibility inhibits the occurrence of aerial sickness and, on the other hand, when aerial

sickness begins, it is very slight so that as soon as it occurs, he will certainly try to land quickly and then the sickness will not become serious. Most student pilots who easily come down with aerial sickness must take precautionary measures to avoid it. Those who have relatively light cases of aerial sickness usually only have dizziness, slight nausea and a weak feeling. The rate of student pilots with this type of slight aerial sickness is relatively high and should be given attention to by teachers.

## II Aerial Sickness and Its Production Mechanisms

The production mechanisms of aerial sickness are relatively complex and the factors are also numerous. The more important of them are vestibular vegetative reactions. There are many factors which bring on vestibular vegetative reactions and threshold acceleration stimulation deserves the most attention. When an aircraft in flight encounters airflow bumping, turning, tumbling and when in various maneuvers, this can produce threshold acceleration action. It is even easier to cause a threshold acceleration effect when a pilot moves his head or body. Aside from this, excessive stimulation by angular acceleration (rotation) of the semi-circular canals, stimulation by the up and down movement and left and right vacillation of the utricle and stimulation by head movements of the lenticular sac - otolith receptor can jointly cause strong vegetative nerve impulses. These impulses pass through the vestibular nuclei, are diffused in the medulla oblongata and then are transmitted to the cerebellum and



hypothalamus which causes the reflex reactions of neck - back and limb muscle tension as well as eye trembling and central reactions such as dizziness. Nerve excitation is transmitted to the medulla oblongata's labyrinth nerve center which further causes a series of labyrinth vegetative nerve reactions including perspiring, slowing of the heart rate, a drop in blood pressure and paleness. When these reactions become more serious, nausea, vomiting, muddled consciousness and respiratory blockage cannot be avoided. It can be said that these symptoms originate from vestibular receptor stimulation and thus cause a series of visceral vegetative nerve reactions. Therefore, in medicine and physiology they are called the vestibular vegetative symptom group. Naturally, during the development of these symptoms, they cannot be separated from the restricting action of the cerebral cortex on the lower center. When these symptoms develop to a serious level, they conversely effect the mechanisms of the higher nerve center.

When the visceral and somatic receptors are subject to angular acceleration and threshold acceleration movement stimulation, this can cause vegetative nervous system reflex reactions and the most important among them is the action of stomach stimulation. Therefore, fullness and excessive hunger easily cause motion sickness. The reason for nausea when motion sickness occurs is, on the one hand, due to the medulla oblongata vomiting center being affected by vestibular nuclei excitation impulse diffusion and, on the other hand, originates from

the reversed peristalsis of the duodenum and stomach. The frequent occurrence of reversed peristalsis causes disorders in the functioning of the vegetative nervous system including the medulla oblongata vomiting center. Nausea and vomiting both signify that vegetative nervous system function disorder has already reached a serious level.

Furthermore, the medulla vestibular nuclei excitation diffusion to the third, fourth and sixth cerebral nerve nuclei or the rotation and shaking of the field of vision cause eye trembling and can also sometimes bring about vegetative reactions.

It must be pointed out that the human body is an organic whole and when its physiological functions are in disorder and not yet in an absolutely harmonious or disintegrated state, the reaction of the human body to acute stimulation is not likely to be limited to one organ or one system and even less so can the reacting organ induce nerve fluid action to affect the whole body. Trying to observe the diffusion of the vegetative nerve reaction and the subjective feelings caused by the afferent nerve pulses to the cerebrum compels and wills the temporary action of inhibiting motion sickness. However, special odors and the hearing of other people being nauseous and vomiting can induce symptoms of airsickness and with these facts people must naturally acknowledge the complexity of the mechanism that brings on motion sickness. In this section, we will only discuss the essentials of the vestibular vegetative reactions.

It is also necessary to explain that although many factors can advance the occurrence and severity of aerial sickness, not all are primary so that their remote and secondary causes must be clearly distinguished and these cannot be spoken of together. For example, a lack of oxygen, a deficiency of fresh air, a hot environment, poor digestion, body discomfort, hunger, overeating and sadness can all promote aerial sickness, yet these factors are not the major cause of aerial sickness.

### III Methods for the Prevention and Cure of Aerial Sickness

The major negative prevention and cure of aerial sickness is medicine while the more important positive prevention and cure is training.

#### 1) Training for Motion Sickness

Motion sickness can be prevented by means of training. Very experienced pilots rarely have motion sickness because flight practice produces training results. It was proven in aviation practice that the former commonly used rotation seat employed for rotation training and simple rotation training were not ideal for preventing and overcoming aerial sickness. During the last few years, many aviation units have tended towards the use of threshold acceleration training. Specifically, this is rotating in a turning chair or continually moving the head according to a fixed sequence while on a four pillar swing. It was practically proven that this type of training is effective for preventing and overcoming aerial sickness. For example, each day while

rotating on the turning chair or swinging, the head was bent forward, raised back, inclined to the right and inclined to the left 7-8 times or the above mentioned head movements were continuously performed until they felt dizzy. This was practiced continuously for 7-8 days and endurance to motion sickness more than doubled. Besides this, constant physical exercises on a swing, gyrowheel, double rings as well as rotation and swimming are advantageous.

## 2) Physiological Selection

Because there are great individual differences of endurance to motion sickness, the selection of a person with high endurance to shoulder the responsibility of flight work is also one effective measure for the prevention of aerial sickness. The basic method of selection is the use of threshold acceleration stimulation. The subject is required to sit in a rotating chair and carry out a series of head movements according to a fixed procedure until the subject has aerial sickness. The greater the number of endured head movements the higher the endurance to aerial sickness. A specific example is: as the subject sits in a rotating chair, the chair begins to rotate in a counter-clockwise direction at a speed of 18 cycles/minute and 2 minutes after rotational speed stabilizes, the subject is required to incline his head  $30^{\circ}$  to the left (completed within 3 seconds) and then 2 minutes later returns his head to a vertical position; 2 minutes later, the subject is required to incline his head  $30^{\circ}$  to the right (completely within 3 seconds) and 2 minutes later

returns it to a vertical position. The head is repeatedly moved in this way 8 times. If the subject does not do this 8 times but shows symptoms of aerial sickness then the time in which the head moved and aerial sickness occurred is recorded as his endurance index. Subjects who move their head 8 times and show no symptoms of aerial sickness are approved. This selection method has a specific coincidence rate with later occurrences of aerial sickness. There are also other selection methods which are basically the same as the one above only there are slight differences in concrete methodology.

### 3) Drugs for Prevention and Cure

Selection and training methods can be employed to decrease the occurrences rate to a very low level and if there is conscious inhibition, especially when a revolutionary sense of responsibility dominates the cerebral cortex, motion sickness can be inhibited. Because of this, in principle, it is not necessary to advocate the use of drugs.

At present, there are already some relatively effective drugs for aerial sickness. Chart 2-60 shows the prevention and curing results of some drugs. The index of endurance to motion sickness indicates the numerical value, after the comparative value, when useless drugs (placebos) have been decreased, of the number of times the head has moved up until the appearance of motion sickness when the subject turning in a rotating chair carries out a specific procedure of head movements. The higher the numerical value, the better the endurance to motion sickness

and the more effective the drug. The names of the drugs listed in the chart are:

1. Phenemine, 20 milligrams
2. Miltown, 400 milligrams
3. Peroxy-acid triethyl propantheline, 10 milligrams
4. Peroxy-acid triethyl propantheline, 30 milligrams
5. histamine, 4 milligrams
6. Trimethylbenzene, 250 milligrams
7. Trimethylbenzene, 750 milligrams
8. Scoline, 25 milligrams
9. Pipecoline chlorpromazine, 5 milligrams
10. Pipecoline chlorpromazine, 15 milligrams
11. "EXP 999", 10 milligrams
12. "EXP 999", 25 milligrams
13. Bianluxing\*, 3 milligrams
14. Meclizine (bucclizine), 50 milligrams
15. Meclizine (bucclizine), 50 milligrams + amiline, 10 milligrams
16. Meclizine (bucclizine), 150 milligrams
17. Xi Na La Xin\*, 50 milligrams
18. XiKe Li Xin\*, 50 milligrams
19. Ephedrine, 50 milligrams
20. Benzedrine, 10 milligrams
21. Benzedrine, 20 milligrams
22. Dramamine, 50 milligrams
23. Benzedrine, 50 milligrams
24. Promethazine, 25 milligrams
25. Scopolamine, 0.3 milligrams
26. Scopolamine, 0.6 milligrams
27. Scopolamine, 1.2 milligrams
28. Promethazine, 25 milligrams + ephedrine, 50 milligrams
29. Scopolamine, 0.6 milligrams + ephedrine, 50 milligrams
30. Scopolamine, 0.3 milligrams + benzedrine, 5 milligrams
31. Promethazine, 25 milligrams + benzedrine, 10 milligrams
32. Scopolamine, 0.6 milligrams + benzedrine, 10 milligrams
33. Scopolamine, 1.2 milligrams + benzedrine, 20 milligrams

Some people who take drugs for a long time can have side-effects of dizziness, drowsiness, weakness and faintness. Thus, it is not beneficial to take drugs for a long period of time and it is safer to take them only when necessary. At present, scopolamine is the drug which has been most often used clinically and taking

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\* Chinese romanization given, translator is unable to find English equivalent.

a 0.6-0.8 milligram dosage one-half to one hour before takeoff will cause most sensitive people not to produce motion sickness. This drug should be taken again after about 8 hours. After motion sickness occurs, the taking of belladonna and phenobarbital together has a certain curing effect.

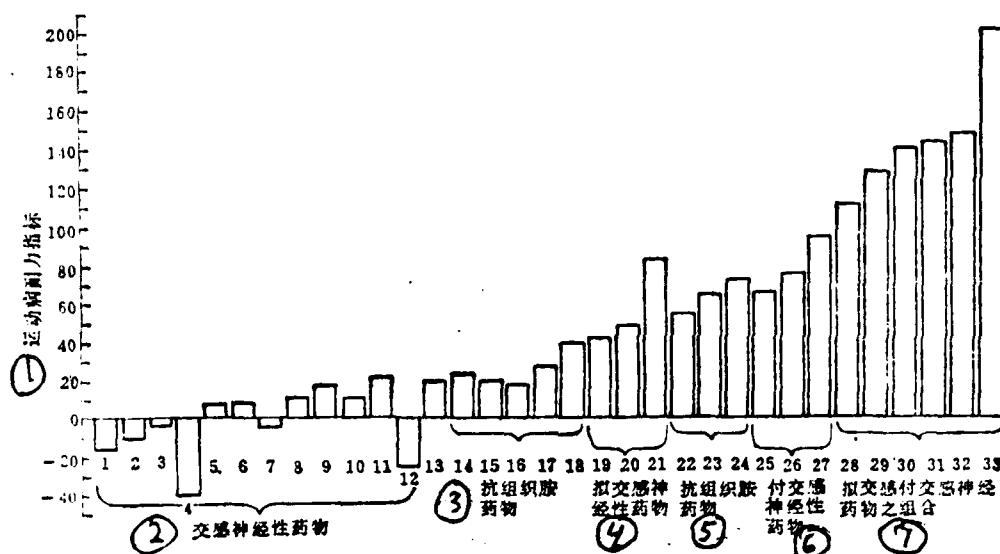


Chart 2-60 Comparison of the Results of Several Types of Drugs for the Prevention and Cure of Motion Sickness

1. Index of endurance to motion sickness
2. Sympathetic nerve drug
3. Antihistamine
4. Sympathicomimetic nerve drug
5. Antihistamine
6. Parasympathetic nerve drug
7. Sympathicomimetic and parasympathetic nerve drug

4) Because aerial sickness often has a specific relationship with head movement (threshold acceleration is produced from this)

in linear or angular acceleration, thus for those pilots more sensitive to aerial sickness, head and body movements are strictly forbidden at this time. To increase control, the use of a suitable head frame or binding straps can provide very good protection.

5) For passengers who are relatively sensitive to aerial sickness, they should take an appropriate amount of anti-air sickness drugs beforehand and it is even better if they can select a seat in the cabin where vibration and bumping is relatively light. When an aircraft is turning, going through clouds, descending to land or has a great deal of bumping and vibration, the passengers should as far as possible decrease movements, especially head movements. When necessary, they should close their eyes, lie on their backs, look at things outside the cabin as little as possible and not become too full or too hungry. Besides these, binding tight the waist also has specific advantages. Those who vomit or even have a loss of water because of aerial sickness should at the right time replenish the physiological saline.



## CHAPTER EIGHT

### FLIGHT ILLUSIONS

#### Section One Preface

Flight illusions by pilots are a common type of space illusion and mainly occur when the pilot's perception or judgment of flight conditions and actual flight conditions do not coincide. For example, when an aircraft is in level flight, the pilot feels that the aircraft seems to be slanted; or when the aircraft is climbing, the pilot feels that the aircraft is in level flight. When flight illusions are relatively serious, errors can sometimes exceed 90°. For example, when an aircraft is in level flight, the pilot feels that he is flying upside down. When a pilot is in the air, he sometimes mistakes the direction (directional illusion) which in aviation terms is called "losing one's bearings." Sometimes a pilot can also mistake objects, for example, mistaking the sky for the sea, the stars for a wing plane or enemy plane and these are called recognition illusions.

Flight illusions are an important problem in aviation and are especially important for fighter planes where they cannot be overlooked. They not only affect flight quality and fighting power but are undeniably one basic reason for flight mishaps.

Based on the investigative statistics from many nations, flight mishaps caused by flight illusions occupy 14% of all flight accidents and among these, major accidents caused by flight illusions occupy 6-9% of major accidents. Fatal accidents caused by flight illusions reach as high as 15-26%.

Flight illusions are rather common phenomena that occur in night flights, instrument flights, stunt flying and in complex meteorological flights such as when flying in wind, clouds, rain, snow or mist. Based on facts divulged in the investigative data from many countries, 90-100% of fighter plane pilots have had flight illusions. Because civil aircraft do not perform stunt maneuvers, and training and flight is relatively level and stable, there are fewer illusions yet about half of the pilots have had flight illusions. The results of a past investigation of 51 civil aviation pilots showed that more 14 experienced flight illusions, that 27.4% and there were a total of 74 illusions. The investigative reports of many foreign nations have disclosed that in the last ten and some odd years, the new aircraft have new equipment, new technology and new developments but that the types and rate of occurrence of flight illusions has bascially not changed. This signifies that flight illusions do not decline following the development of new technology and new equipment in aircraft. On the contrary, new flight illusions occur because of the development of new types of planes. For example, the illusions caused by the flash motion of helicopter wings.

## Section Two    Circumstances of the occurrences of Flight Illusions

Flight illusions are commonly named after the specific circumstances that occur. For example, when the aircraft gradient perceived by a pilot does not coincide with the aircraft's actual gradient (exceeding the general range of perception error), this is called inclination illusion and when the perceived aircraft pitching angle does not coincide with reality, this is called pitching illusion; when the position of the aircraft has already changed and the pilot still cannot perceive it, this is called non-perception of flight position change; and when one type of object (for example, stars) is mistaken for another type of object (for example, an aircraft), this is called recognition illusion.

Inclination illusions occur most often and occupy over one-half of all flight illusions. Second is non-perception of flight position change which occupies about 10% of the total number. Following these sequentially are pitching, rotational, distance (including altitude), directional and recognition illusions. Some civil aviation pilots have more distance illusions which is verified by the data in table 2-22.

① 错觉种类	② 出现次数	③ 占总次数(%)	④ 出现错觉的人数	⑤ 占总人数(%)
⑥ 倾斜错觉	38	51.4	8	15.7
⑦ 距离(包括高度)错觉	20	27.0	1	2.0
⑧ 飞机状态变化未感觉到	7	9.5	2	3.9
⑨ 俯仰错觉	4	5.4	2	3.9
⑩ 旋转和反旋转错觉	2	2.7	1	2.0
⑪ 共 计	74	100	14	27.4

Table 2-22 Classification and Frequency of Flight Illusions by  
51 Civil Aviation Pilots During a Given Year

1. Type of illusion
2. Number of occurrences
3. Number of times within total (%)
4. Number of persons who had the illusion
5. Number of people within total
6. Inclination illusions
7. Distance (including altitude) illusions
8. Non-perception of flight position change
9. Pitching illusions
10. Rotation and counter rotation illusions
11. Total

It is also necessary to point out that illusions in sea-going aircraft are more numerous than those in land aircraft, including altitude, time and distance recognition illusions. Each type of illusion can occur among 60% of pilots.

### Section Three      Conditions that Produce Flight Illusions

The production of flight illusions is related to human and environmental factors. The former can be viewed as the internal cause while the latter is the external cause. The external

causes arise from the actions of the internal causes.

I. The Major Factors of the Objective Environment are  
Day and Night, Meteorological and Cabin Conditions  
and the Geographical Environment

(1) Day and Night, Meteorological and Geographical  
Environment

Complex meteorological and night or darkened cabin instrument flight illusions are relatively numerous. The occurrence rate of night complex meteorological flight illusions is several tens to several hundred times higher than those during common daylight meteorological conditions. In comparing night and complex meteorological factors, the latter often have a more dominant effect on flight illusions. Furthermore, sea and desert air easily cause illusions.

(2) Cabin Environment

An aircraft's cabin environment also affect illusions. Instruments that are poorly designed, reflecting points and signal lights that are excessively strong and powerful flashing lights can all easily cause flight illusions. When aircraft instrument and control arrangement is too decentralized, it is often necessary for pilots to turn their heads and move their bodies to a relatively high degree for observation and operation and this easily causes illusions and aerial sickness. In an aircraft with instruments, covered light in the cockpit, a pilot's binding straps, poor equipment, uneven pressure, a bad seated posture and an uneven seat cushion are also primary and secondary causes that

bring about illusions.

## II. The Pilot's Major Conditions are Jointly Called Internal Causes

### (1) Flight Experience

Pilots who have ample experience in complex meteorological, stunt and night flying have relatively few flight illusions. If they do occur, they can be controlled and overcome. A pilot whose flight technique is lacking and moves carelessly easily produces illusions.

### (2) Health and Physical Exercise

Those whose health is poor and who incur motion sickness (aerial sickness) easily produce flight illusions. Close to one hundred percent of those with histories of cerebral oscillation, light headaches, insomnia, unstable blood pressure, poor equilibrium, unsatisfactory adaptation to darkness and epilepsy can have flight illusions within one year. Those pilots who do not undergo regular physical exercise have even more flight illusions. Exhaustion, poor rest and defective vision easily bring on illusions and initial period illusions a certain time after flight has stopped are also relatively numerous.

### (3) Subjective Activities

All those who encounter external causes that cause illusions and bring the initiative of subjective activities into full play can often control illusions which have already occurred and with logical judgment overcome them.

Flight illusion is a type of judgment perception error and is due to incomplete data being transmitted to the cerebrum from each peripheral receptor and the contradiction which occurs between them cannot be unified; the function of the two hemispheres of the cerebrum and the receptors is unbalanced; and at the same time because the cerebrum is influenced by the past experiences of life on the ground, it cannot distinguish clearly present experiences with those of the past and thus has errors in judgment. This is the mechanism of flight illusion. When a pilot's flight technique is relatively mature and his subjective activities are strong, there will be few flight illusions and when they occur, he can overcome them. This is because he can satisfactorily bring into play the comprehensive and dynamic action of cerebral analysis, is not confused by surface images and has correct judgment. This is not due to any particular superiority in his sight and vestibular receptors in his body.

#### Section Four    The Causes for the Production of Flight Illusions

The mechanism of flight illusions has been detailed in the previous section and below we will further discuss the causes for its occurrence.

There are two categories of information sources for flight illusions: one is visual and one is vestibulo-main body. In most cases, vision occupies a dominant position because in man's daily

activities and movements vision occupies a governing position among the various organs. This is because its impressions of environmental objects are the most meticulous and precise. Although vestibulo-main body perception is not precise, yet it is the source of information for the postures and movements of the body and in this sphere it is essential and has special functions. Because of this, from a diagnostic viewpoint, we must recognize that they are mutually related, mutually contradictory, mutually complementary, mutually influential and are integrated. It is also necessary to emphasize that the reasons for illusions of received signals and errors in cognition are due to the inability to correctly integrate the contradictions of various types of signals. How is it that they cannot be correctly integrated and thus create errors in judgment? This is because there is a discrepancy between the signals in flight and the experiences of life on the ground or because few or more of these mutually related signals have been experienced so that the cerebrum cannot correctly discriminate the primary and secondary and takes the inaccurate signals as leading signals. Aside from this, imbalance of the receptors and the mechanism of the two hemispheres of the cerebrum can sometimes cause errors in comprehensive analysis. Based on the above principles, we will separately narrate in detail the sources of these two categories of illusions.

#### I. Visual Causes

There are many visual causes that bring about flight



illusion and several major types are listed below.

(1) The Effect of Field of Vision

In man's life on the ground, the state of the field of vision of the surrounding environment is important information for determining the state of the human body. When field of vision inclines to the left, one feels the body is inclining to the right; when the field of vision is reversed, one feels the body is suspended upside down. Actually, on the ground very few people encounter inclined field of vision and thus the head or body do not bend toward reverse inclination. Because of this, people can accurately judge the field of vision and vestibulo-main body signals. In flight, one can sometimes encounter non-homologous fields of vision and aircraft conditions which run counter to the customary relation of experience and signals and this causes errors in signal conformity. For example, sometimes when an aircraft is flying in or under clouds, a person feels that their field of vision is not straight because the clouds are oblique. This creates the illusion that the aircraft is in lateral inclination towards the clouds, yet in reality the aircraft is in level flight. Further, if an aircraft is in sea-going flight, because of the blurriness caused by the mist over the sea, a pilot sometimes feels as if the sky and ground line is shifting up or down wherein he mistakenly thinks that the aircraft nose is diving or ascending which produces pitching illusions. These types of flight illusions are too numerous to mention individually.

## (2) The Effect of Light Rays

During flight, when on one side the light rays are very bright and the other side is very dark, for example a high illumination light, sunlight, moonlight or a strong light shining in from one side, or when the cockpit in an instrumental aircraft covers the light on one side, these situations can cause the illusion that the body (of the aircraft) is laterally inclined or pitched toward the strong light. This is because in most situations on the ground light rays radiate from above the human body or are usually stronger above the field of vision so that when the light below the field of vision is relatively weak, the direction of the strong light becomes the signal of vertical judgment (the zenith). Pilots called this the "comfort of wearing light on top of the head". During night flights, when the ground target lights are relatively concentrated (as in a city) and on the other side the lights are sparse (as in the suburbs), these types of situations can cause a person to feel that the aircraft is inclining to the side where the lights are concentrated. This is because the denser lights and clearer ground targets cause the judgment that the altitude is on the low side.

## (3) Illusions in Depth (Distance and Altitude) of Vision

Our visual judgment of the distance (or altitude) of objects is determined by many physical and physiological clues. The important clues of distance judgment are the size, shape, brightness, color and moving speed of the object. These physical

factors all make impressions on the retina and from this there is coding which transforms into nerve impulse signals. After the signals are transmitted to the cerebrum, they undergo analysis and finally there is distance judgment. Objects that are large in size, clear in shape, bright, radiant in color and move quickly are generally perceived as being close. How do flight depth of vision illusions occur? We think that they are errors in judgment because the physical and physiological clues that appear during flight are not completely identical to those on the ground and when using ground experiences to judge conditions in the air, mistakes cannot be avoided. Below we give several examples to prove this.

a. When an object (ground target) becomes visibly clear and the area of the image increases, this causes the illusion of the object as being close in distance, otherwise there is the illusion of the object being far away. Snowy or water surfaces, illuminated ground targets as well as very strong runway lights at night in an airport can easily cause very low estimations of altitude and thus produce illusions in landing an aircraft at too high a level. On the contrary, when the lights are dark and visibility is lacking, altitude judgments tend to be high. During formation flight or when tracking targets, if the lead aircraft or target aircraft changes position and causes the visual image to become suddenly larger, then it is easy to have the feeling of sudden closeness. On the contrary, when the visual image suddenly shrinks, then there is the feeling that the

distance has suddenly become greater. The main causes of these types of visual illusions are because during most daily living situations on the ground, when visual clarity of an object becomes distinct or the visualized image becomes larger, this means that the distance of the object has become closer. These two types of signals often become important signals for depth perception. In the air, depth perception signals are scarce and when the data changes and the actual distance change of an object do not correspond, distance illusions easily occur.

b. Depth illusions are also often caused by visual habits (visual constants). One example is after a long high altitude flight, if a person suddenly descends to land, altitude judgment often tends to be low. This is because the further the object is from the eyes, the smaller the visual impression formed on the retina. A person in daily life has already made a firm connection concerning the above mentioned corresponding changes of the object's distance and the size of the visual image so that when in high altitude flight, although the visual image of the object on the ground is very small, yet because of the effect of visual constancy the object on the ground is said to be close to its actual size. When an aircraft descends quickly, this type of visual constancy is difficult to eliminate all at once, and therefore it is easy to take the object on the ground as relatively large and, moreover, the appraisal of the distance of the aircraft from the ground tends to be low.

c. Contrast illusion is also a common type of visual illusion. For example, when there is a small object next to a large object, the large one is perceived to be even larger and the small one is perceived to be even smaller. When a bright object is on a dark background, it seems even brighter than it actually is. In the same way, while flying over level ground for a relatively long time, when an aircraft rapidly approaches a high mountain, the mountain can easily be taken as being higher than it actually is.

#### (4) Visually Imagined Movements

After a not very large object is looked at for 30 seconds in an empty field of vision (an empty structureless field of vision such as a cloudless clear sky and a black night sky), most people feel as if it is making irregular movements. The speed and range of this type of movement can be very large, can occur in any place, speed and distance and can cause one to mistake targets for stars or stars for targets during fighting.

#### (5) Relative Movement Illusions

The fixed position of visual relative movements depend on a great many physical and physiological clues. The correct analysis and arrangement of clue signals is the basis of correct perceptual judgment. During flight, because there are few clues and because the contradictions of the clues (signals) cannot be unified, illusions are produced. When in formation flight, the speed and directional changes of the movements of the lead and one's own aircraft are easily confused and judg-

ment is not accurate. Furthermore, when an aircraft comes near to a high mountain, a cloud or the earth's surface, a pilot sometimes feels the high mountain, cloud or earth's surface is shifting closer to the aircraft. When flying in clouds or at night, one sometimes feels as if the aircraft is not moving or conversely, when flying in clouds one sometimes feels the aircraft speed is excessively fast. The various illusions mentioned above mainly occur when clues for the judgment of an object's movements are very few and when there is no static object to act as a reference point. Therefore, this type of illusion easily occurs in an empty field of vision.

## II Vestibulo-Main Body Causes

There are many vestibulo-main body factors which cause the production of flight illusions and the major types are discussed below.

### (1) Rotation and Counter Rotation Illusions

When rotation begins and as soon as it ends, a person can have rotation and counter rotation illusions that last for a few seconds to a few minutes. When an aircraft turns, pitches or rolls and there is fixed angular acceleration, it can also bring about these types of rotation and counter rotation illusions, thus causing the pilot's perceived aircraft altitude not to coincide with the actual altitude.

### (2) Threshold Acceleration Illusions

When an object makes a linear movement in a rotating space,

because it simultaneously changes its rotational radius, its linear movement speed changes and because of this acceleration is produced which is called threshold acceleration. When an aircraft turns or has inclined and pitching angular acceleration, if the pilot moves his body or head, such as raising his head to look outside the cabin or lowering his head to see the instruments, this will cause threshold acceleration. Threshold acceleration stimulates the vestibular labyrinth receptors and thus causes the illusion of the body falling, doing somersaults and tumbling, and finally causes motion sickness.

### (3) Illusions Produced by Overweightness

When an aircraft is in rectilinear or radial acceleration (the centrifugal force produced by an aircraft spiraling or making a large turn), the overweightness produced by the centrifugal force of acceleration and the earth's gravitational force form a resultant force. The direction of this resultant force and the direction of the earth's gravitational force form an angle. At this time, the direction of this resultant force's vector acts in the direction of the earth's gravitational force and becomes major data for vertical judgment. This produces inclination illusions or the inclined aircraft is perceived to be in level flight.

(4) Vestibulo-main body analyzers are not very sensitive to and accurate in experiencing altitude changes and there can often be errors and delays. Moreover, after a specific time of altitude change there can be adaptation and various illusions are created

from this.

For example, sometimes when the inclination of an aircraft is not yet perceived and when the aircraft turns to level flight, the pilot often feels as if the aircraft is inclining in the opposite direction.

(5) Vision and vestibulo-main body analyzers\* can produce high tendency excitability phenomena on one side of the body because of a mechanism imbalance on two sides of the human body, and this also causes illusions. Some pilots are very stubborn about illusions and this is possibly one reason for it.

The contradiction of vision and vestibulo-main body perception is an important cause of flight illusions. Vestibulo-main body perceptions are not very precise, as mentioned previously. This is determined by the physiological characteristics of this system's receptors. During daylight, when the weather is good, people usually use relatively precise vision to judge the distance, size, speed and direction of a substance and vestibulo-main body perception acts to identify the position of one's own body which often occupies a leading position. Yet, when a perception signal is produced that is different than usual, another signal can rise to occupy a dominant position. When vision irregularity occurs, help can be sought in vestibulo-main body

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\* The term analyzer is used by the Pavlov School and it indicates the activities of related peripheral receptors and a nuclei group of the central nervous system.



perception. If the actions of various accelerations cause vestibulo-main body perceptions not to coincide with the objective real environment and thus are mutually contradictory with visual signals, this causes space direction to be complex and confused, correct judgments are difficult and it is ultimately difficult to avoid illusions. Conversely, if vision and vestibulo-main body signals are mutually contradictory, a pilot who has a great deal of air experience and is accustomed to depending on the information read on the instruments for data on space direction, can overcome this type of contradiction. Therefore, when the contradiction of visual signals of the natural environment outside the cabin and the vestibulo-main body perceptions of one's own body cannot be coordinated, the pilot must believe the instrument signals.

Although it is difficult to use will to control and overcome illusions caused by vestibulo-main body receptors, this is only relative and not absolute. Subjective activity cannot be overlooked in the area of overcoming illusions.

#### Section Five      Methods for the Prevention and Overcoming of Illusions

To decrease flight illusions, pilots, space navigation physicians and medical workers have proposed many medical preventative measures. Below we will only mention the principal ones.

1) The adoption of various methods for educating pilots to correctly recognize the characteristics, causes and certainty of

flight illusions, break free from all misgivings, master all possible techniques for their prevention and elimination, and raise ability to read instruments and their confidence in the instruments.

2) The strengthening of technical training in instrument flights, night flights and complex meteorological flights including ground practice and flight training.

3) Persevering in physical exercise, especially physical exercises to strengthen and raise endurance to motion sickness.

4) Paying attention to tying the safety straps well, arranging the seat cushion evenly, avoiding uneven left and right pressure on the body and avoiding non-upright postures during flight. When moving during angular acceleration, it is necessary to avoid fast and large movements of the head and body and as far as possible avoid excessive brightness from shining on one side of the cabin.

5) Know exactly all the possible situations that produce illusions and prepare well for them. Peruse the instruments often and judge flight conditions based on instrument readings. If one becomes dubious of the instruments because of illusions, the pilot can use the mutual check in the instruments and carry out suitable operations to test the accuracy of instrument reactions so as to strengthen his confidence in the instruments.

6) Strengthen the sanitary safeguards and medical tests for pilots and make sure that the pilot has a strong constitution and healthy physique. It is usually necessary to pay attention to

rest and avoid liquor, overwork, insufficiency of sleep or insomnia.

7) When selecting pilots, it is necessary to pay attention to the problem of endurance to motion sickness, because a person who easily gets motion sickness, easily produces illusions.

8) Excellent political character and distinctive proletarian revolutionary will are important for controlling and eliminating flight illusions. Therefore, it is necessary to continuously carry out political and ideological education.

When illusions occur, the following measures can be adopted to eliminate them.

1) Analyze and clearly recognize the causes of illusions and act to negate them. Have firm confidence in the instruments and correctly determine the aircraft's condition according to the instruments. In this way, illusions can be eliminated.

2) After illusions appear, the pilot should avoid confusedly applying large corrective operations. He should be sure to calmly and resolutely discriminate the aircraft's position based on the instruments and as far as possible use gentle movements to correct the aircraft's conditions.

3) Keep clear of illusion-related information, for example, avoid staring at the sky-ground line when over the sea and the inclination of clouds.

4) When necessary, the attention can be shifted. For example, moving the body, gritting the teeth, tensing the muscles, looking at unrelated scenery, shouting loudly several times and conversing

with ground connections. This shifting of attention is sometimes beneficial to weakening or eliminating illusions.

5) After illusions occur, a pilot should immediately report to the leading aircraft and the control tower. The commander should verbally instruct the pilot to have confidence in the instruments and how to eliminate illusions.

Finally, it must be emphasized that although the above mentioned measures for preventing and eliminating flight illusions are effective and cannot be neglected yet it cannot be denied that they are still not the fundamental means for preventing and eliminating flight illusions. In order for the pilot to clearly recognize the causes, characteristics and mechanisms of flight illusions and through his own personal experiences and practice eliminate them, the best method is training wherein flight illusions are produced and eliminated in ground practice aircraft and various environmental factors are simulated to produce illusions in an aircraft. The adoption of this type of training can raise a pilot's recognition of flight illusions and raise his ability to control and eliminate them. This is the most basic and effective channel for preventing and eliminating illusions.

## CHAPTER NINE

### MAN'S ADAPTATION TO WEIGHTLESSNESS AND LOW WEIGHT

#### Section One Preface

##### I. Fundamental Concepts

Weightlessness and low weight are relatively particular types of physical conditions in space navigation. Weightlessness is when there is a complete lack of gravity wherein an object (including the human body) is totally without weight and low weight is when the earth's gravitational force is low so that the weight of an object is lighter than on earth.

When an object moves freely (powerless movement) in a vacuum, even if it is in a gravitational sphere, it never has weight and is then weightless. When a fighter plane is in parabolic flight and when a spaceship is in powerless, free flight in outer space, weightlessness occurs. When a person jumps out of an aircraft, before the parachute opens, he is a free falling body in the air and thus experiences weightlessness. In the same way, when a person descends in an elevator, he also experiences weightlessness for a very short time. It can be seen that weightlessness can also occur on the earth's surface but the time is very short and often is not even noticed. Because weightlessness is quite long during space navigation, it has a more outstanding effect on the human body and thus catches people's attention.

Besides the existence of weightlessness during free flight, when an airship orbits the earth or another celestial body, for example the earth orbital flight of a man-made satellite type spaceship or a spaceship orbiting the moon, weightlessness can also occur because its centrifugal force corresponds to the gravity of the earth or moon and furthermore they counteract each other (because the directions of the two are opposite).

The gravity of certain celestial bodies is smaller than that on earth. For example, the gravity on the moon is one-sixth that of earth's and because of this, after a spaceship lands on the moon, low weight is encountered.

Weightlessness or low weight are not only encountered in space navigation but astronauts must remain in this state for long periods of time. Because the human body is not accustomed to this type of state, a series of mechanical disorders cannot be avoided. It is necessary to go through a period of adjustment after which one is able to completely adapt. However, after complete adaptation, there can also be a period of non-adaption when returning to earth and thus it is necessary to again adjust mechanism to adapt to life on earth. This process of adaptation and return adaptation is an important problem for special environment medical science.

## II The General Situation of the Human Body in Weightlessness

Weightlessness is an outstanding problem in space navigation as long time weightlessness is generally not encountered on

on the earth's surface. Because of a lack of learning through practice, very early people made many conjectures and hypothesized that weightlessness could possibly cause sleep and serious blockage of the cardiac blood vessels and the digestive and excretory systems. In recent years, actual experience in space navigation has shown that when a person lived in a weightless state for 3 months, no serious physiological impediments occurred and that the effect of weightlessness on the human body was actually not very serious. After appropriate protection, training and adaptation, a person could completely adapt to weightlessness for several months.

In light of actual experience in space navigation, the major effects of weightlessness on the human body are included in three general areas.

- 1) Weightlessness causes the gravity load of the cardiac blood vessels, muscles and skeletal system to lighten and after a long period of time, it possibly causes the load capacity of these tissues and organs to weaken. Thus, there is an obvious decrease in the human body's endurance to earth gravity and overweightness. Weightlessness is quite similar to lying on a bed for a long time without moving. The major method for eliminating these types of effects is suitable and regular physical exercise which causes the load of cardiac blood vessels, muscles and the skeletal system to be suitable and this avoids the weakening or decline of load capacity.

- 2) Weightlessness causes the human body to lose water and

calcium. The latter is possibly directly related to decreasing the gravity load on the musculo-skeletal system. After there is an excessive loss of calcium, the bones become loose and weak and moreover this further lowers the human body's endurance to the earth's gravity and overweightness. Because of this, besides appropriate and regular physical exercise, it is also necessary to coordinate this with protective measures of food nutrition and when needed, specific drugs can also be utilized.

3) Weightlessness has specific effects on flight capability but the effects are mostly temporary and thus, after a specific amount of adaptation time, there can be recovery or elimination. When in a weightless state, there is difficulty in space direction and some people produce flight illusions and space sickness (also called weightlessness motion sickness). This is especially evident during the initial period of weightlessness. For example, operation efficiency declines and operation errors increase. The special feature of weightlessness is that the human body is not stable and so as soon as a person is swayed by a very small outside force or the body makes a small movement by itself, there is excessive swaying and shifting. Since actions and operations are very uncustomary, strength is either too great or too small. After undergoing training in aircraft with weightlessness and simulated weightlessness, the human body's ability to adapt to weightlessness is greatly strengthened. To help actions and operations in weightlessness, human body engineering measures such as equipment to assist actions can also be used (see later section for details).



## Section Two    The Physiological Effects of Weightlessness

### I.    The Effects of Orbital Flight on Cardiac Blood Vessels and the Respiratory System

When a spaceship is in orbital flight around the earth, the basic course of cardiac blood vessel and respiratory system changes is: when there is overweightness during the lift-off of a spaceship, the heart rate, respiration rate and blood pressure usually rise and when there is weightlessness, they quickly regain their normal level prior to flight. During the initial period of weightlessness, fluctuations can be seen in the heart rate, blood pressure and respiration rate. These fluctuations are possibly related to nerve tension and when there is weightlessness for several hours to one day they can return to normal. After over one month of space navigation, fluctuations can also appear in the cardiac blood vessel and respiration indices, yet these do not exceed the normal fluctuation ranges of the human body. This point is verified by the data presented in charts 2-61 and 2-62. During the course of weightlessness, the heart rate and respiration rate drop slightly yet, after continuous orbital flight, they gradually rise again. It can be seen from this that there is possibly an adaptation process of cardiac blood vessels and the respiratory system to weightlessness.

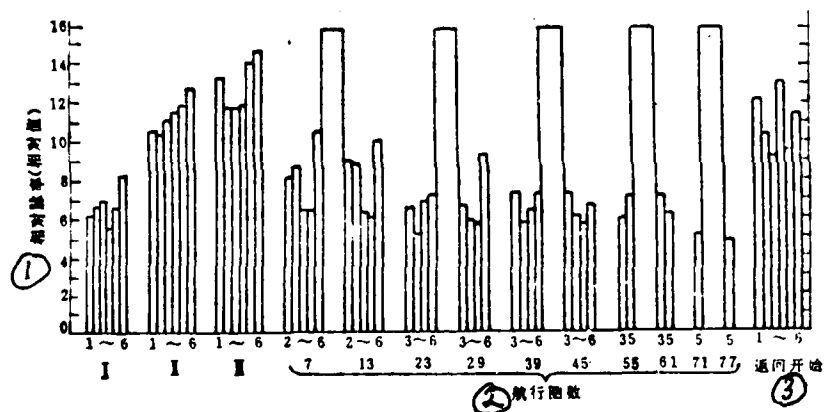


Chart 2-61 Relative Pulse of an Astronaut When Asleep and Awake

Numbers 2-6 separately represent 6 astronauts; I - 4 hours before navigation; II - 5 minutes before navigation; III - period when navigation begins (the powered flight period); the long and wide empty lines represent the sleeping period.

1. Relative pulse (relative value)
2. Number of orbits
3. Return begins

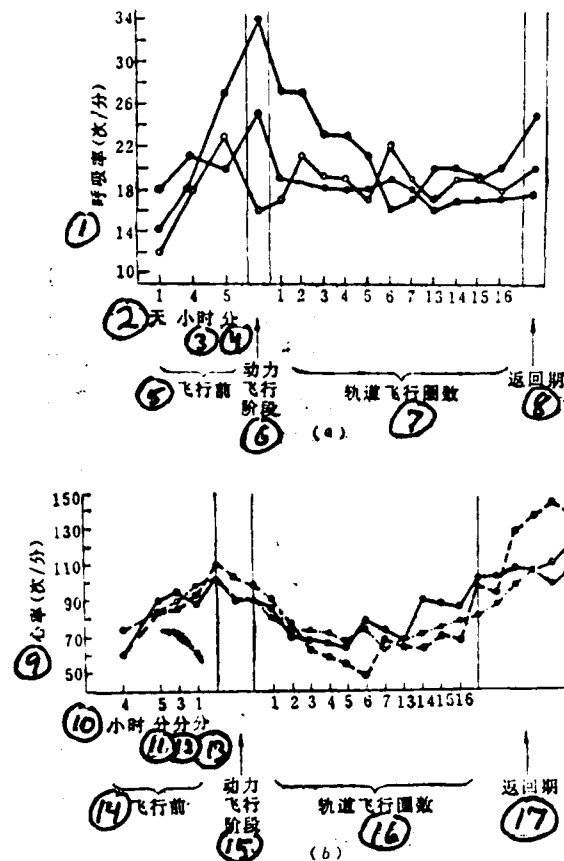


Chart 2-62

Respiration Rate (a) and Heart Rate (b) during Space Navigation (the Three Curves Separately Represent Three Astronauts)

1. Respiration rate (times/minute)
2. Days
3. Hours
4. Minutes
5. Before flight
6. Powered flight period
7. Number of orbits
8. Return period
9. Heart rate (times/minute)
10. Hours
11. Minutes
12. Minutes
13. Minutes

14. Before flight
15. Powered flight period
16. Number of orbits
17. Return period

When astronauts in navigation leave the cabin and move about, carry out tense operation activities as well as just before returning to earth, their heart rate, blood pressure and respiration rate indices often rise and a minority of astronauts show changes in their electrocardiograms such as ventricular extra systole and premature pulse. This is also possibly related to operation activities and nerve tensions which is not necessarily caused by weightlessness. When in space navigation, the heart rate and respiration rate drop during sleep and the tendencies are the same as those during normal sleep on earth. It can be said that up until the present, from the results of actual observations of space navigation for 3 months, when suitable protective measures were taken, the effects of weightlessness on cardiac blood vessels and the respiratory system were actually very slight and were without any danger.

Under weightlessness, because the lungs lose weight, the diaphragm shifts upwards and the force of respiration lightens and there is a tendency for respiration volume and pulmonary breathing to increase. Furthermore, because the blood loses weight and goes up towards the head and upper half of the body, the head and nose fill up with a certain amount of blood and this causes the chief complaints of a feeling of blood filling the head and stuffy nose. However, after several days of weightlessness, these complaints gradually decline which shows that

the respiratory effects on the human body caused by weightlessness can be adapted to and regulated.

The manifestation of the effects of weightlessness on the blood were contradictory and different for each astronaut. These types of differences were certainly related to the fact that the composition of their respired gases were different and the circumstances of their water losses were different. Furthermore, it cannot be overlooked that the sensitivity level of each astronaut was different. Water loss causes blood volume to decrease and navigation for several days to several tens of days can cause plasma volume to drop 7-13%. However, there are many reasons for water loss such as work and mental tension, forgetting to drink water and high temperatures. After medical inspection which stress a system for drinking water and drinking water until full, water loss is greatly decreased or is eliminated.

## II     Drinking, Eating and Excretion Under Weightlessness

The problem of taking food under weightlessness has caused people great anxiety. Some people fear that after small pieces of food or dry powder enters the oral cavity, because of the swaying brought on by weightlessness, it will fly into the nasal cavity or wind pipe and cause choking. During the course of the food descending from the esophagus, it is also possible for the food to float up from the esophagus thus causing nausea and upper abdominal discomfort. During the initial period of space navigation, people tended to think that astronauts should place half jellied food in a flexible tube and squeeze the flexible tube into the

mouth. However, actual experience has shown that under weightlessness there are no difficulties in taking food in pieces, slices, liquid and jellied form. To prevent the food from floating away, it cannot be placed in a dish in unlimited amounts but chopsticks or spoons must be used to place the food in a specially made utensil such as a flexible tube or plastic bag. When taking food, one slice at a time should be placed or squeezed in the mouth. This type of method requires that the food first be prepared on the ground and stored in the spaceship. Under weightlessness, when cutting the food into small pieces there is the possibility of it floating away and so it is necessary to cover the pot. Specially made utensils are necessary for frying meat and vegetables and if they are not used, the meat and vegetables will float in the pot and not touch the bottom of the pot.

How is water taken under weightlessness? People have tried three methods for taking water in short time weightless flights: (1) the use of a cup; (2) sucking through a straw; (3) squeezing a capsule into the mouth. Investigations have shown that the use of a cup is unsuitable because when the water flows from the cup it immediately floats into the air and splashes into the face or is even sucked into the nose, thus causing blockage. Method (2) which uses a straw also won't work because air and water are easily sucked into the mouth and since water easily congeals into globular shapes, the sucked in air is greater than the water that is taken in. Only method (3), the squeezing of a capsule into the mouth is a good method for drinking. Results of

experiments have been successful in space navigation and thus this method has been used.

During the first two or three days of space navigation, digestion disturbances are due to being unaccustomed to the space environment and mental tension. During sleep, there is a lowering of liquid secretion inhibition and stomach and trypsin activity. It can be seen from this that a good method would be to take a drink to promote a desire for food, which is very necessary. Even if the time of navigation is long, when an astronaut becomes accustomed to the environment, digestion will not be disturbed again but it is still necessary to maintain a good method for taking food.

For the problem of urination under weightlessness, some people have carried out tests in aircraft while in weightless flight. Testees drank a large amount of water beforehand and were ready to urinate prior to weightless flight. Test results showed that individual reactions varied; some people when urinating lost the pressing feeling; some people's urination was normal; when some people urinated they had gastric disorders because of abdominal tension and vomited; and some people who had no visual aids found it difficult to guide the urine. The loss of the pressing feeling of the urine was possibly due to the urine losing weight which weakened the pressure on the triangular muscle in the bladder and also possibly due to mental tension during flight where the attention was focused on maneuvers which inhibited the feeling of a desire to urinate. It should be known

that not only was the duration of weightless flight very brief but also before and after weightlessness there was overweightness. The alternation of weightlessness and overweightness cannot completely represent the actual situation of space navigation weightlessness. Therefore, these results can only act as a reference. The actual experience of astronauts has shown that their pattern of excretion on the ground was often disrupted during the initial period of navigation and feces and urine remain in the body longer but that excretion was not felt to be especially difficult. Naturally, in order to prevent feces and urine from floating and decrease the stench, special bags or vessels must be used to storage the excrement.

Space navigation observations and investigations have shown the following few facts: during the first orbit, the amount of urination generally increases, the number and quantity of bowel movements decreases and after two orbits there are noticeable improvements. This signifies that the disturbances to the excretion mechanism can be adapted to and restored.

During the course of space navigation, there are changes in the composition of the urine, yet after navigation there are no irregularities in the functions of the kidneys. Urine composition changes are related to the food composition and substance metabolism at the time and are not created by changes in the functioning of the kidneys.



### III. Mineral Metabolism, Osteoporosis and Lightening of Body Weight

Osteoporosis brought about by weightlessness is a major change in the structure of the human body that occurs during space navigation and which cannot be foreseen. During the initial period of space navigation, there is a lack of use of suitable protective measures due the proportion of people who do not understand the situation and as a result the occurrence of osteoporosis after space navigation is very common and also quite serious. For example, after 4-14 days of space navigation, the thickness of finger bones decreases more than 8-24%. Animals in spaceships and people in ground simulated weightlessness also experienced this type of phenomenon. The following conclusion can be drawn from these observed facts: osteoporosis is a physiological effect of an organism to weightlessness.

There is no doubt that in metabolism, osteoporosis shows changes in mineral metabolism primarily in the increased release and discharge of calcium, sodium and potassium. When an astronaut has navigated for less than one day and not taken suitable precautions, there is an increase in the amount of calcium discharged in his urine. When navigating for a longer period of time, this phenomenon continues to develop and there is a discharge increase of both calcium and potassium. After over ten days of navigation, the discharge rate of potassium, sodium and phosphorous tends to increase for some astronauts.

During research on ground simulated weightlessness while

lying on a bed, it was discovered that the amount of calcium discharged in the urine increased. For example, when lying on a bed for six cycles, the calcium loss in the whole body was 1-2% and when lying on a bed for four cycles calcium loss was 0.5%. When lying on a bed and not moving, the average rate of calcium loss was 0.7-1.3% per month. However, calcium elimination while lying on a bed was generally less than during space navigation.

Ground simulated weightlessness and actual experience in space navigation have both shown that the increase in calcium discharge is a temporary phenomenon. Following long time adaptation to the conditions, there is finally a tendency towards stability. Generally speaking, the high point of organism elimination of calcium occurs under weightlessness for about one and a half months.

Osteoporosis and organism elimination of calcium under weightlessness is possibly related to the lightening of the skeletal load and decrease in activity. A rise in the rate of mineral secretion not only effects the bones and muscles but can also effect other physiological functions such as cardiac excitation, blood coagulation and anticoagulation, lipase activity, and adenosine triphosphate urinary nuclei and proteinase activity. There are some people who think that it possibly causes kidney stones. It goes without saying that a relatively important direct aftereffect of osteoporosis is that bone load capability declines and thus decreases body strength load capability and antiover-

weightness capability. Decrease in endurance to overweightness effects the safe return of an astronaut to earth.

After suitable physical exercise, calcium replenishing and other measures, the elimination of calcium and osteoporosis caused by weightlessness can be greatly decreased and improved. The lowest limit can cause there not to be any effect of weightlessness on bodily health and work ability and overweightness when the spaceship returns will pose no danger to bodily safety.

When astronauts return to earth there is a certain lightening of body weight. Records concerning 55 foreign astronauts show that after navigation, body weight decreased 0.5-4.5 kilograms which occupied 0.7-9% of their total body weight. After using a good menu to control food and seriously taking physical exercise and rest time, body weight loss during navigation can be improved and individual astronauts had insignificant weight decreases. The reason for body weight decrease is partially due to muscular atrophy and elimination of calcium from the bones. For example, a minority of astronauts often have shrinkage in the shank area during weightlessness which for some people reaches 8-12%. After returning to earth and taking ample and nutritious food, their body weights were quickly restored. It can be seen that water loss is one major reason for body weight decrease. Mineral loss and loosening of the bones is also certain. From animal and clinical observations on the ground it was seen that long time non-activity and very little activity of the muscles can also cause muscular atrophy. Fortunately, space

navigation has already taken these problems into consideration and required that astronauts undergo serious physical exercise and thus these problems can be said to be solved.

#### IV. The Effect of Weightlessness on Body Power Load and Endurance to Overweightness

Long time weightlessness can cause declines in body load capability. This can be anticipated and thus scheduled medical safeguards have eliminated this shortcoming. Before astronauts return to earth or orbit the moon they necessarily sustain overweightness. If after a long period of weightless space navigation endurance to overweightness declines, then when returning to earth, operation capabilities can be poor which is a problem worthy of attention for medical guarantees.

After a long period of weightlessness, there can be inadaptability to normal earth gravity which is especially noticeable in the reactions of the cardiac blood vessel system. Tests in the commonly used upright posture (the body position changes) have shown this. During the test, the subject lies level on a flat board, after a specific amount of time the flat board is turned upwards 70° towards the head and in 10-20 minutes blood pressure is measured. If systolic pressure drops and diastolic pressure rises this shows that the blood cannot overcome the earth's gravity and flow back into the heart and that the heart cannot push out the blood returning to the heart. This reaction is quite sensitive. This is a simple, effective method to test the physiological reactions of astronauts to gravity. Besides this, the negative

pressure in the lower half of the body can also be tested. In this test, the lower half of the body is placed in a specially sealed compartment and later the pressure in the compartment is decreased 10-80 millimeters on the mercury column. Within 15-30 minutes the heart rate and blood pressure are measured. The results are identical to the above method. During these two types of tests, the stronger the blood pressure, the less the endurance to the earth's gravity. After the astronaut returned to earth, results of these types of measurements showed: after several days of navigation, there was an evident decline of endurance to the earth's gravity which explained that the physiological reaction of accustomization to weightlessness was at its peak and thus there was a strong and unstable reaction to the earth's gravity. Chart 2-63 shows the cardiac blood vessel changes during a test in an upright posture. Each chart, from left to right, uses vertical lines to separate three stages: tests before an upright posture, during an upright posture and after an upright posture.

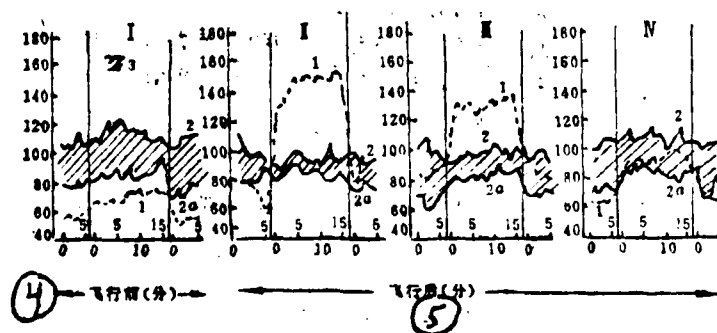


Chart 2-63 Comparison of the Results of Upright Posture Tests on Astronauts Before and After Navigation  
(Key-next page)

1. Heart rate (times/minute)
- 2,2a. Blood pressure
3. Pulse pressure (millimeters on mercury column)
4. Before flight (minutes)
5. After flight (minutes)

After relatively long navigation, upon returning to earth and leaving the cabin, some astronauts show facial paleness, upper respiratory tract mucosa hyperemia, sclera blood vessel hyperemia, light swelling of the eyes, the pulse rate reaches 120 times/minute, the pulse is full and uneven, arterial systolic pressure is 140 millimeters on the mercury column, diastolic pressure is 90-100 millimeters on the mercury column, and standing and walking are difficult. This shows a temporary inability to adapt when changing from weightlessness to gravity upon returning to earth and this causes physiological reactions similar to those of overweightness. The major complaints of astronauts are feelings similar to those under 2-2.5 G positive overweightness and feelings of exhaustion and weakness. When standing, there is dizziness and when lying down they feel that their four limbs and internal organs are heavy. These situations often require several days of readaptation before they can return to normal. Some astronauts think that this type of readaptation is even more difficult than adaptation to weightlessness. Generally speaking, the longer the period of navigation, the lower the endurance to the earth's gravity and the longer the time of readaptation.

Actual tests on astronauts have also shown that after a long period of weightlessness there was a noticeable decline of

endurance to overweightness. If there is a lack of suitable protection and training experience for weightlessness by an astronaut, the physiological reactions to overweightness during return to earth will be stronger than before weightlessness and will be difficult to endure; when weightlessness lasts for a relatively long period of time, physiological reactions to overweightness will be stronger. When endurance to overweightness decreases, some ingenuity is needed for recovery. The major reasons for the above mentioned phenomena are the temporary inabilities to adapt to the changes of the environment and the most important is naturally the change from weightlessness to overweightness. Yet, it is not the sole reason because during navigation mental tension and lack of physical power for activity are also related to it.

It goes without saying that because of the lack of physical power for work during navigation, after the astronaut returns to earth he cannot avoid certain declines. When working, the heart rate, discharge of carbon dioxide and respiration quotient are all higher than before navigation. Arterial systolic pressure and average pressure are both higher than before navigation and diastolic pressure drops. The time needed for restoring blood pressure is lengthened and the amplitude of the electromyogram becomes smaller. This series of changes requires several days to over ten days before returning to normal.

After a long period of navigation, not only do upright posture tests and physical power load endurance decrease but there is a varying degree of defect maintained in a continued balanced

position and steadiness of actions. This is because the astronaut is not accustomed to sudden changes in gravity and at the same time this is closely related to osteoporosis, muscle weakness and a decrease in endurance to the earth's gravity.

In order to avoid or decrease the above mentioned unhealthy effects, it is necessary to strengthen physical training, provide suitable foods and thoroughly implement a system of work and rest. In this way, after returning to earth, reactions to overweightness and the earth's gravity can be close to normal and even if there are halting movements they will not be serious.

#### V. The Effect of Weightlessness on Sleep

Experiences of astronauts in space inform us that during navigation sleep is relatively good; this is very important for restoring vitality. Individual astronauts had space sickness but after sleep, the symptoms usually took a turn for the better. Generally, during the first few days of navigation, sleep time was more or less the same as that on earth. However, during longer navigation, the sleep time for some people gradually shortened.

Although sleep time in space navigation gradually decreases, for example when it decreases from 7-8 hours before navigation to 5-6 hours, yet this does not cause any decline in energy. Most astronauts and medical safeguard personnel think that it is not good for an astronaut to sleep less than 6-7 hours, otherwise it will to some extent effect that days energy and work efficiency.



However, it should be pointed out that the depth of sleep and sleep time are equally important; if sleep is not deep but the astronaut sleeps a little longer, cerebral rest will possibly be insufficient; on the other hand, if sleep is very deep but sleep time is a little shorter, cerebral rest is actually relatively fuller. In other words, when considering the problem of sleep, time and depth must both be considered.

Section Three     The General Feelings of Weightlessness and their Effects on Flight Capabilities

I. The General Feelings of Weightlessness and Space Sickness

There are great individual differences of people's feelings to weightlessness. Because up to now, the number of people who have gone into space is not great, most research data in this field comes from research on aircraft in weightless flight.

Aircraft weightless flight is also called parabolic flight. The specific course is: the aircraft first has a climb acceleration (the acceleration value is about 2.5 G) and after reaching a specific rising speed, acceleration stops and the aircraft enters a stage of powerless free flight wherein its locus becomes a parabolic shape. Chart 2-64 is a figure of its locus.

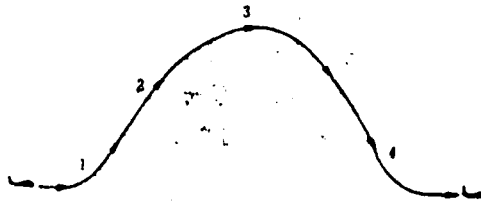


Chart 2-64 Locus of an Aircraft in Weightless Flight

A plane entering parabolic free flight is equivalent to a free falling body and the aircraft and the objects in its cabin enter a weightless state. When an aircraft falls to a specific altitude and pulls out and changes to level flight, during the course of pulling out the aircraft sustains about 2.5 G acceleration. After it enters level flight, deceleration stops and then the aircraft enters normal flight. The use of this type of weightless flight can produce several seconds to several tens of seconds of weightlessness. Because the time of weightlessness is short and because sustained acceleration and deceleration before and after weightlessness is about 2.5 G, there is a certain difference with the long time stability of space navigation. However, because at present manned space navigation is still difficult to carry out on a large scale, aircraft in weightless flight is still a relatively good method for studying weightless-

ness and training for weightlessness. At least it is more real than the simulated weightlessness of being immersed in water or lying on a bed.

Based on a series of studies on aircraft in weightless flight, the general feelings of man in weightlessness can be divided into the following three types.

1. People With Good Reactions

Under weightlessness, they feel rested, slow floating, satisfied and comfortable, relaxed and happy. When they open their eyes space direction is good and when they close their eyes they have slight directional difficulty. Work ability does not noticeably decline. In repeated weightlessness they continually feel happy and there are no negative reactions. Sometimes these people have a slight feeling of unsettling or itching in the abdominal area. There is slight vertigo and the eyes have feelings like those just mentioned.

2. People With Medium Reactions

When under weightlessness, they feel their bodies are floating, falling or rising or turning over toward the front or back. At the same time, they feel that they are suspended upside down. They do not feel happy but do not have any serious discomfort. When they open their eyes, direction is slightly impaired and when they close their eyes it is even stronger. Respiration becomes quicker and is somewhat difficult. There is slight vertigo and nausea and they feel hot or cold. After flying, they are exhausted and desire to sleep, they have no self control and nervous disorders. After 12-15 occasions of weight-

lessness flight training, the discomforting feelings can completely disappear.

### 3. People With Bad Reactions

Under weightlessness, they feel their bodies are floating, are suspended upside down or tumbling forward and backward, their heads are light or heavy and their abdomens are uncomfortable. These feelings of discomfort are progressive. There is motion sickness with autonomic nerve symptoms including skin, paleness, sweating, dry throat, an increase of saliva, feelings of being cold or hot, vertigo, nausea and vomiting. Some people think that these types of gastric disorders which cause nausea and vomiting are related to the fact that the internal organs do not descend again and that substances are floating in the digestive tract. Thus, they are called "weightlessness gastric disorders" and are considered symptoms of "spacesickness". People who suffer from this type of bad reaction often require 20-30 times of weightlessness flight training whereupon the unhealthy reactions are decreased or disappear. However, there are a minority of people who continually find it difficult to eliminate the symptoms of space sickness.

Based on statistics, the first type of person occupies 40% of the total, the second type 23% and the third type 30%.

In the above mentioned classification, most tests used data of aircraft in weightless flight as the basis and there was a correlation with weightlessness in space navigation. However, actual tests actually show that some people's reactions to weight-

lessness are relatively good and that some people's reactions are deficient. These situations show that the selection of astronauts who have suitable weightlessness reactions are worthy of consideration.

Actual experience in space navigation has shown that during the initial period of navigation there tends to be many astronauts who have space sickness but the symptoms are generally light. Among the symptoms, the most numerous are stomach discomforts and secondary are feelings of the head filling with blood, nausea and vomiting. Besides these, there are also those who have space direction illusions, yet, after a specific time of adaptation, the symptoms can disappear. In reality, all those who undergo aircraft weightlessness training can avoid the above mentioned discomfort reactions. However, some people require more training while some people only require a small amount of training.

## II The Problem of Perception Under Weightlessness

Verbal reports by astronauts show: when most are in orbit, perception ability is still good; instrument reading, ship operations, writing, taking photos, radio communications and machine examination and repair are all normal, and the abilities to see, hear, smell and taste do not show any irregularities. However, these reports can only act as references. Below we will introduce tests results as a means for comparison.

### I. Vision Changes Under Weightlessness

Measured results during orbital flights of the visual

sensitivity of astronauts in different brightness contrasts have shown that under high brightness contrasts, when an astronaut only occupied a 1.4 rectangle of a 0.2 inch arc, he could clearly recognize his position but he could not do so on the ground. A spaceship that carries out visual, hand control air rendezvous maneuvers is required to land on the moon because the lunar module is launched by its mother module (command module) and the mother module continually orbits around the moon, waits for the lunar module to make a return rendezvous and afterwards returns to earth. Besides this, air rendezvous also requires space laboratories and long term space stations to provide air supplies, astronauts to shift duties and the carrying out of air maintenance. For example, a 14.6 centimeter diameter balloon is launched from a spaceship, the balloon has two neon lights which alternately flash each second at a 1 radian angular speed. In orbital flight, the balloon moves back and forth, sometimes towards the spaceship and sometimes away from it. Tests results show that the flashing lights on this balloon can be seen clearly at a distance of about 13-22 kilometers and at a distance of 26-27 kilometers they are dark and difficult to see clearly. In order to test people's visual capabilities, a bright orange balloon with a 76 centimeter diameter was launched from a spaceship and at a distance of 30 meters the astronaut was not only able to find it but was also able to take a moving picture of it. Based on the above observed data it can be seen that under weightlessness vision is generally normal.

## 2. Brightness Discrimination and Visual Illusions

Under weightlessness, the brightness discrimination threshold seems to be better than on earth. Studies done on aircraft in weightless flight show that the low light brightness discrimination threshold is 12.6%<sup>F.N.1</sup> under weightlessness and 15.1% during level flight. The brightness discrimination threshold of medium brightness is 6.5% under weightlessness and 7.05% in level flight. Under high brightness the numerical values are separately 3.39% and 4.45%.

When there is weightlessness, people feel discomfort and during the initial period of weightlessness there can also be illusions including figure enlargement, figure illusory movements, changes in the strengths of color and luster and the shining of a brilliant light on the periphery of a figure. A subject can sometimes have illusions for several minutes.

## 3. Hearing, Taste and Smell

Changes in hearing under weightlessness are not great. There are slow reactions in taste and smell and rises in the taste threshold such as the tastes of sweet and sour becoming bland.

F.N. 1 The brightness discrimination threshold % is calculated by the following formula:

Brightness discrimination threshold % =

the numerical value of the smallest brightness  
change that can be distinguished  
numerical value of basic brightness

This is possibly related to the contact between the food and taste buds under weightlessness and signifies that an astronaut's flavoring of his food should be different than on earth.

#### 4. Perception of Time

When carrying out activity under weightlessness, some people have a tendency to have a low estimation of activity time while others give it a high estimation. How does this discrepancy occur? The great majority of people who estimate low are those who have health reactions to weightlessness and most of the people who estimate high are those who have discomfort reactions.

#### 5. Space Direction

Under weightlessness, the vestibulo-main body receptors lose their normal state of receptivity to a great extent and therefore when closing the eyes an astronaut finds difficulty or is even unable to discriminate between the vertical and the oblique. Very great difficulties occur in space direction and because of this, when an astronaut performs activities outside the module, if the spaceship is not within a person's peripheral vision, solely relying on memory to determine the relative position of the spaceship and individual is not very possible or totally inaccurate because the spaceship has moved and time has already passed, and past recall cannot substitute for the present. During the initial period of weightlessness, it is easy to have space direction illusions because there is more blood flowing to the head and there is a feeling of a lack of lower body pressure. Sometimes this can even cause the illusion of being suspended upsidedown. Actual experiences of astronauts confirm this. When



there is weightlessness and the human body floats in the air, an astronaut who closes his eyes cannot carry out space direction very well. Yet, if the body is fixed in a chair and the eyes are closed, an astronaut can accurately carry out fixed position activities with his hands and there is no difficulty in motor coordination. Astronauts who do not have vestibulo-autonomic reactions do not generally have position illusions and those who do have these reactions possibly produce position illusions. For example, one astronaut reported that during the first night of orbiting around the earth, when he raised his head to look out of the module, he seemed to be able to see the sky but was unable to see the horizon so that he thought the spaceship was suspended upsidedown and later, after careful observation, he realized this was incorrect. Another astronaut reported that during the initial period of entering weightlessness, he felt that some of the furniture had changed position; even though his body was tied in a chair he still had the feeling that he was going to float up; although he was lying on his back, he felt he was sitting vertically and another time he felt his body was suspended upsidedown.

### III      Movements    and Activities Outside the Module Under Weightlessness

The major difficulties of movements under weightlessness are: the body floating and loss of support; besides this, when changing from being accustomed to weight to weightlessness, limb

movements often have excessive strength which causes the astronaut to be unable to maintain his normal body position and state and this promotes floating and toppling over. In order to improve this situation and overcome these difficulties, whether moving about inside or outside the module, certain implements and devices are needed to aid movements. We will first introduce the observed difficulties in movement of astronauts in weightless orbital flight without the aid of special implements and devices and afterwards will introduce several types of devices used for aiding movements.

#### 1. Major Complaints Reported During Movements in a Module

Below we will only mention several cases. For example, some said: "After leaving the module, we felt the spaceship was floating to one side and our body was floating to the other side. To sum up in a word, there were no differences in reaction to weightlessness inside and outside of the module". They said: "Movements were easier outside the module than inside the module and actions returning into the module were more difficult than those needed to get out of the module". They pointed out that when pulling on a rope (safety rope) in outer space to move nearer the module, the strength needed to pull with the hands was difficult to accurately control and if greater strength was used, they collided with the spaceship. When the body was stabilized a great deal of effort was required. When they first left the module, if their bodies collided with the module, this caused their bodies to to turn on their longitudinal and latitudinal axes. Afterwards,

the body's turning speed was slowed down by reversing the safety rope. When the body was rotating, although they could not see the spaceship, still the bearing of the spaceship was basically maintained. However, when the spaceship was not within peripheral vision, space direction was definitely difficult or inaccurate. Yet, they still mainly relied on the relative position between their bodies and the spaceship. In order to help space direction, some people proposed that different parts of the spaceship should have different colors or marks as a means of distinguishing them.

When astronauts leave the module to do work, their body positions are unable to be stable because their bodies are floating in the air and therefore work is difficult and strenuous. For example, once when an astronaut was given a task to do outside the module, he had to join the air duct on the module wall outside the spaceship with the tube on his space suit so as to receive air feed<sup>F.N.1</sup>. Yet, after leaving the module, he found it difficult to become fixed because of body floating and thus had to expend a large amount of energy to join the tubes. It can be seen from this example that joining tubes, which is easily done on earth, can also present major difficulties. This also signifies that if no suitable device aids or other measures are used for

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F.N.1    There is no oxygen in outer space and therefore people must take oxygen from a tube connected to the inside of the spaceship so as to maintain air pressure and temperature inside the space suit.

work done under weightlessness outside the module, the work will be very inconvenient. A further example is when an astronaut's task outside the module is completing ship docking<sup>F.N.2</sup>. After leaving the module he felt movement along the spaceship was difficult. In completing the assigned task, it was difficult for him to maintain his position. The specific task was to join the stop rope (ship cable) of the target spaceship with the docking equipment of the mother ship and afterwards twist the rope tight with the hands to bring the two ships close. Although the task was completed, he felt it was very difficult so that he seemed to exhaust all his energy. Because of this, improvements were made in later spaceships. When working under weightlessness, great results are attained if ways are found to use binding straps and foot clamps to fix the body.

It can be seen from the several examples mentioned above that if no implements are used to aid movements and work operations under weightlessness, it is difficult to complete tasks. Below we will introduce several types of devices for aiding movements under weightlessness.

#### 1. Safety Ropes

This was the earliest used and is the simplest type of device. Strictly speaking, it is a solid long rope which connects an astronaut's body with the body of the spaceship. This can

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F.N.2 Docking is the bringing close and joining of two spaceships. This is required for most navigation, aerial supply, substituting people, maintenance and rescue, all of which has already been discussed previously

prevent the human body from floating too far from the spaceship. If by chance an astronaut has difficulty in space direction he can rely on the rope to return to the spaceship. An astronaut can also pull the safety rope to help his movements in outer space and it can also be used to steady the body when it turns. Safety ropes are generally joined from the space suit to the spaceship's gas duct.

## 2. Foot Clamps and Handgrips

In order to help the astronaut affix his body and thus aid in operations when servicing the spaceship, some spaceships arranged "foot clamps" in work places. Before astronauts start work in work places, they first clamp their feet tightly in "foot clamps" and thus stop the body from floating. Handgrips are also devices for affixing the body which can be used when the body is moving. After using these auxiliary devices the body will not float again when an astronaut is in operations outside the spaceship module and he will make good use of his energy. Foot clamps and handgrips can also be installed inside the spaceship module as devices for the astronaut's movements inside the cabin and for affixing the body.

## 3. Magnetic Shoes

For movements within the spaceship module the use of electromagnetic soles fitted on the bottom of shoes can be considered. The floor of a spaceship is made of iron sheets so that an astronaut wearing this type of shoe under weightlessness

can walk on the floor. However, it is necessary to undergo previous training before being able to walk well.

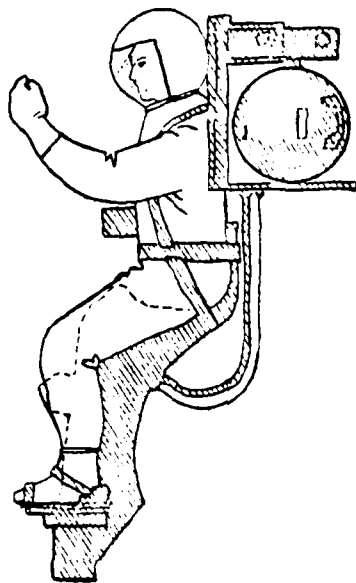


Chart 2-65 Devices for an Astronaut's Movement Under Weightlessness

#### 4. Jet Module and Back Binded Movement Accessory

See chart 2-65 for the back binded movement accessory. An astronaut uses his hand to pull the controller which allows his body to have free movement in all directions within space (including shifting and turning). The device is moved by compressed gas and the spherical ball that the astronaut wears on his back is a gas case.

Besides this, if under weightlessness there is no rope or handgrip, then an astronaut can only use his own body movement to turn. Generally speaking, a person under weightlessness can rely on waving the arms and legs to shift or turn the body.

Waving the legs is more effective than waving the arms. When the hand is holding a heavy object then there is a noticeable raise in efficiency for moving the body. Charts 2-66 and 2-67 are pictures of using waving arms and legs to move the body under weightlessness. All of these require preliminary training before a person can control their use.

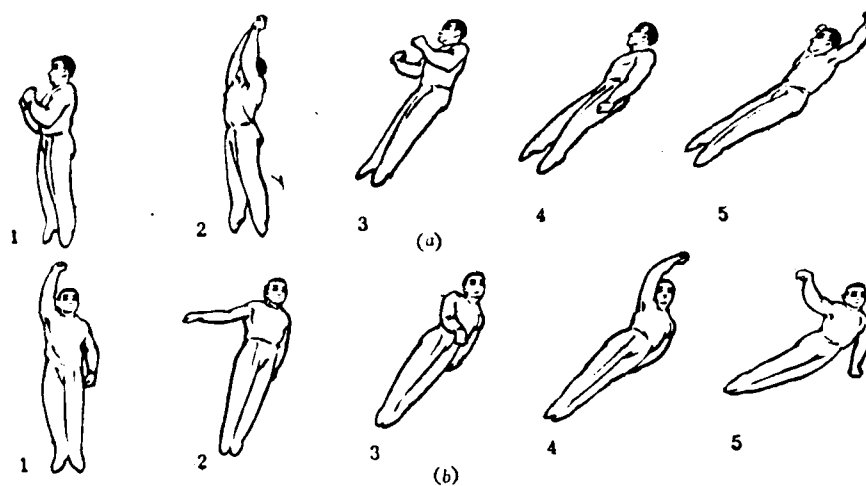


Chart 2-66 Examples of Waving the Limbs for Movement Under Weightlessness

Charts a and b are examples of two series of movements

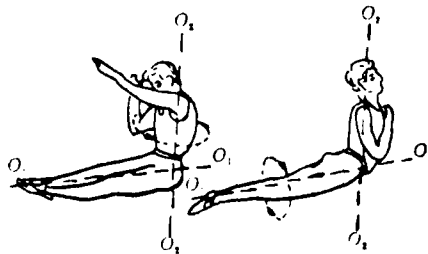


Chart 2-67 Pictures of a Series of Movements Using the Spinning Rotation Body Method to Change the Body from being Bent to being Level and Straight under Weightlessness

In the chart,  $O_1$  and  $O_2$  separately indicate the directions of two body axes.

Chart 2-68 shows figures of an astronaut standing on the ground in a disc with an arc shaped bottom training to wave his limbs in order to move his body. In the chart, two rows of pictures have the body leaping in the air to carry out the above mentioned training positions. In chart 2-68,  $a_1$  and  $a_2$  separately show a person standing on discs with arc shaped bottoms carrying out two series of movements.  $b_1$  and  $b_2$  separately show two series of movements using waving limbs for movement in the air after a body jump off the ground.



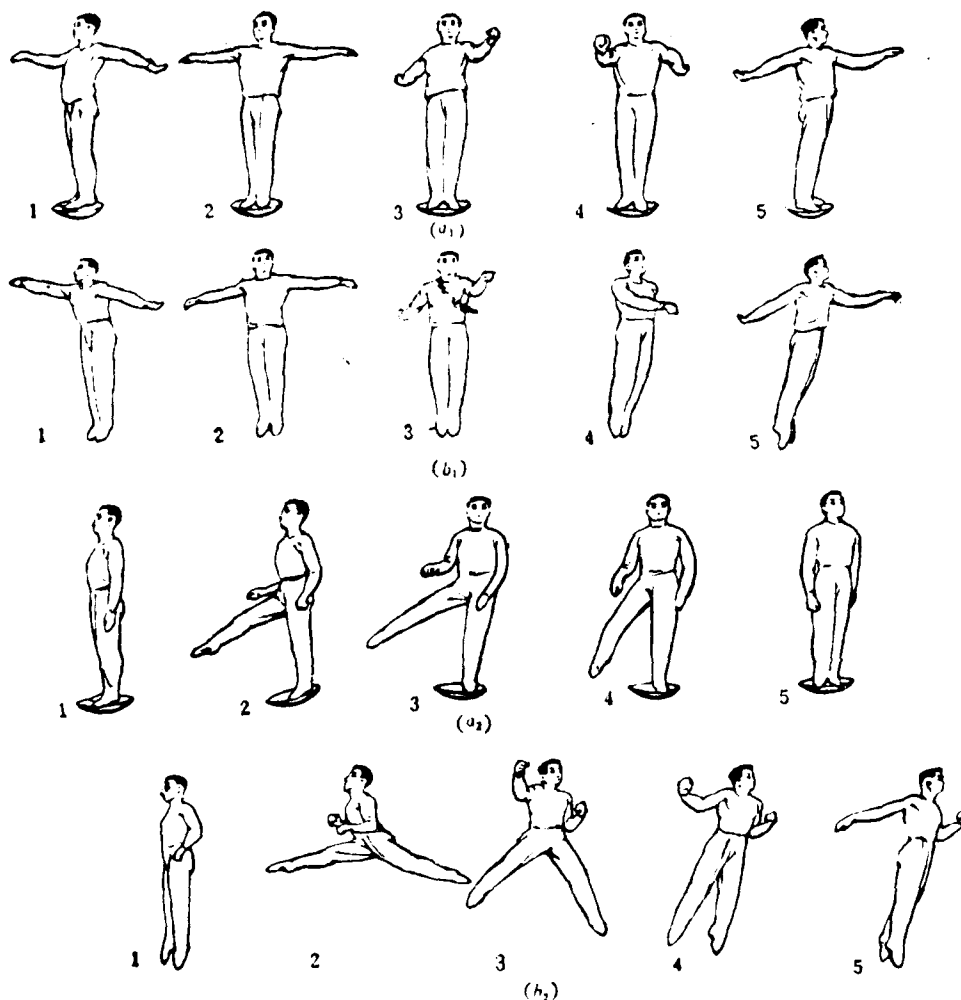


Chart 2-68 Methods of Ground Training Under Weightlessness  
Using Waving Limbs for Movement

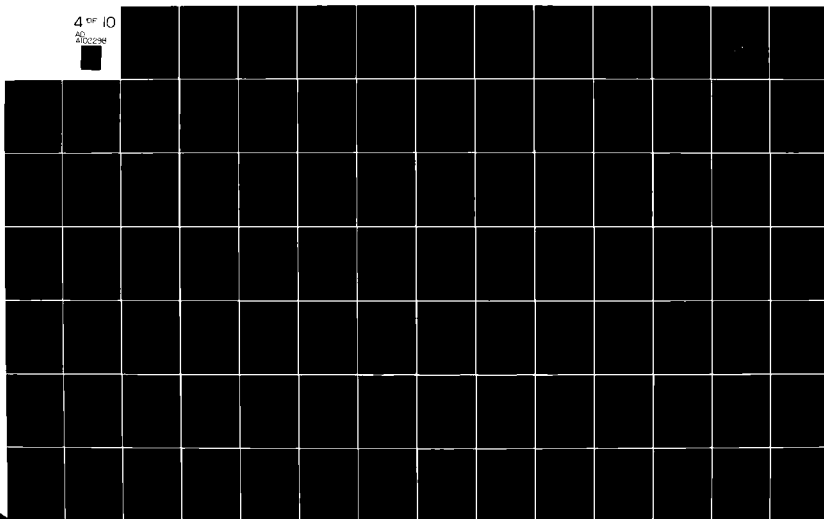
#### IV Movements on the Surface of the Moon

The major problem of movements on the moon's surface is low weight because the moon's gravity is only one-sixth that of the earth's. The effect of low weight on the human body is generally not large yet movements can have their special features.

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When standing on the moon's surface with low weight, the range of body swaying enlarges; the bend angle of leg joints can increase about  $10^\circ$  and when walking the body inclines forward a little - see chart 2-69. The left side of the chart is the stance when on the earth's surface (normal gravity) and the right half of the chart is the stance on the moon's surface. The numbers under the charts indicate walking speed (meters/second).

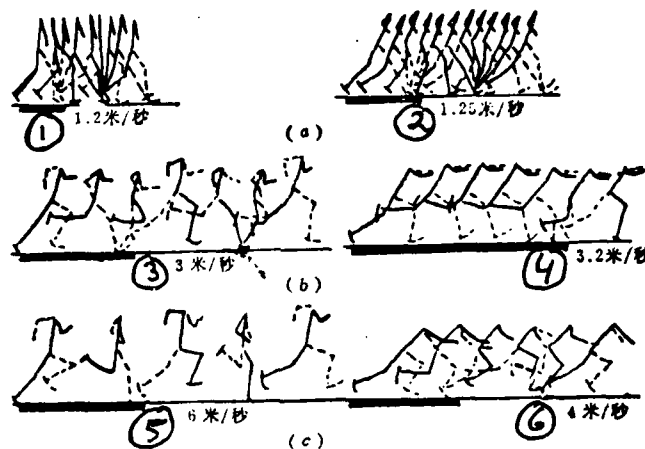


Chart 2-69 Schematic Drawing of Walking Positions on the Moon's Surface

- a. Walking
- b. Jumping
- c. Running
- 1. 1.2 meters/second
- 2. 1.25 meters/second
- 3. 3 meters/second
- 4. 3.2 meters/second
- 5. 6 meters/second
- 6. 4 meters/second

The rhythm of leg movements is relatively slow which is

possibly related to the body's center of gravity falling after shifting upwards when walking under low gravity. When walking, the steps are relatively small and the speed is quite slow. However, jumping is easier than under normal gravity; the height and distance of jumps increases. Jumping on the moon can be six times higher than on earth and distance is about double. Because of this, a better method of walking on the moon is taking jump type steps. This is fast, saves energy and forward advance can be quicker than on earth. With the use of these types of steps metabolism is generally lower than when running. The difficulty of lower gravity walking under low weight is less than on earth and after the load is increased, steps can be more normal and convenient. Under the gravity of the moon, when jumping with a heavy object, the resulting steps can be similar to walking and running on the earth's surface. The difficulty of walking while wearing a pressurized space suit is also less than on earth and the difficulty completely disappears.

The major complaints of astronauts walking on the moon basically correspond to the above mentioned conditions. Some say: "The gravity of the moon is one-sixth that of the earth's yet the weight of objects seems to be only one-tenth its weight on earth.....When a person is walking on the moon, their subjective feelings seem to be similar to those while walking on earth. When wearing a space suit on the moon walking is not any more difficult than normal walking on earth". They felt walking on the moon was more relaxed than walking on the earth. If the hand

held or the back sustained a heavy object of 74-78 kilograms when wearing a pressurized space suit, walking was still very relaxed.

Incidentally, the moon's surface has a very thick layer of dust which is about 10-20 centimeters thick. Therefore, when walking on the moon the feet can sink but because the moon's gravity is one-sixth that of earth's a person does not sink very deep and there is no excessive difficulty in walking.

#### V The Effect of Weightlessness on Operations

There is a noticeable effect of weightlessness on operations control and precision control because when people are accustomed to operations activities under the earth's gravity, as soon as they enter a weightless environment, muscle strength is temporarily difficult to control and people temporarily cannot smoothly control their direction and range of movements. Therefore, they must undergo a period of adaptation and suitable training before being able to gradually overcome this. Below is a simple introduction to some manifestations of these effects.

##### 1. Muscle Strength

When people float under weightlessness, they find it difficult to exert strength and this exertion is often excessive with the result that the body shifts position and floats. When there is weightlessness, exerting strength for operations requires the use of binding straps or foot clamps to affix the body. However, after the body is affixed, muscle power in the

hands is not as strong as on earth, position activities often tend to be above the target and the control of exerted strength for operations is frequently inaccurate.

## 2. Writing

Actual experience in orbital flight has shown that if the body is not stationary, a person cannot complete the task of writing very well but, on the contrary, if the body is fixed to a chair with binding straps there is no difficulty in writing yet the writing speed will be slower. For example, the time needed to write 6 words will be 11-12% longer and the time needed for marking a table will increase 9%. During the initial period, writing is quite poor and the major manifestations of this are: (1) the written characters are not uniform in size, slanted, divided, uneven at the tops and bottoms of the characters and the lines are not neat; (2) the heaviness of the strokes are twisted, angular, turned and form dotted lines. In other words, the precision of five finger and wrist movements drops.

## 3. Flight Operations

When a spaceship is in orbital flight, hand control time is lengthened and the accuracy of operations lowers. Yet, generally speaking, spaceship hand control operations can be completed. The results of tests on tracking operations have shown that operation errors are 13-19% more than those on earth which occur at over 0.5 cycle/second high frequency signal

control. The time needed by an astronaut to complete spaceship angle direction control in orbital flight is also relatively long. However, after an extended period of weightlessness, the decrease in operation efficiency becomes progressively smaller. This shows that the effects of weightlessness on operation efficiency can be eliminated after adaptation.

#### 4. The Ability to Deal With Sudden Accidents

Can the ability to deal with sudden accidents under weightlessness be seriously effected? This can be answered by the actual occurrence of one accident. There was one occasion when a spaceship was flying towards the moon and there was suddenly an electronic breakdown 330 thousand kilometers from earth. At this time, the astronaut quickly climbed into the lunar module and cooperating with the earth control station rectified the spaceship's return air line and finally safely returned to the spaceship. This experience shows that a person under weightlessness can bring into full play his subjective activities to deal with emergency accidents.

### Section Four Protective Measures Against Weightlessness

#### I. Physical Exercise Under Weightlessness

One aspect of the effect of weightlessness on the functioning and organ quality of the human body is the lightening of the load on the musculo-skeletal system causing weakness and possible atrophy. In order to improve this situation, physical exercise is one of the most effective protective methods. However, there

are specific problems of doing physical exercise inside a space-ship module:

- (1) space is limited;
- (2) the body floats under weightlessness and if there is movement it will shift even more.

Because of this, they must carry out movements after affixing the body as mentioned previously. In order to realize this goal it is necessary to design a set of special physical exercises which can be done when the body position is fixed. This is naturally not difficult to accomplish.

Theoretically, a person's physical work capabilities are conditioned by the following factors.

- (1) The nervous system especially the control, conformity and regulation of its higher places. The more this type of mechanism of the nervous system is used the more active it is but when not used it tends to decline.

- (2) The strength, hardness and flexibility of muscle tendons and joints. In order to maintain and strengthen these characteristics, exercise is necessary.

- (3) Reliance on muscle exercise can raise quality and it also strengthens circulation, respiration, digestion, secretion and metabolism.

- (4) At the same time, we must also pay attention to the auxiliary effects of other factors.

The problem is how to design appropriate physical exercises



using the spaceships limited space and an astronaut's rest time. In light of a spaceship's environment and characteristics, soft gymnastics and local muscle concentrated exercises are possibly the most appropriate because these types of gymnastics can be done while seated and fixed in a chair and standing stationary on the floor. In this way, the four limbs, neck and abdominal area can all be separately exercised. It should be stressed that it is best if there are many kinds of exercises. Exercise can be done two or three times a day and each time should not be too long, 30-40 minutes is enough.

It must also be pointed out that stationary gymnastics easily cause lack of interest. The revolutionary will and sense of political responsibility are the most basic and essential motivations for persisting in physical exercise. Without this type of motivation an individual's interest cannot carry out physical exercise very well. If he is able to form a type of exercise beforehand on the ground this is even better because he has already formed a habit which is not easy to change.

Space physicians from various nations have designed many different exercises for astronauts to perform during navigation. Some use rubber and springs on chairs to carry out strong physical exercises and some are formulated for 18 days of navigation wherein each person does the exercises twice daily and each time lasts one hour. The exercises include four sets: the purpose of the first set is to maintain muscle strength and muscle movement speed; the second set is for strengthening muscle tension; the

third set is for raising the human body's general endurance and sustenance; the fourth set uses a specific load to measure physiological parameters. Physical exercise is done wearing an elastic exercise suit using a spring device with a pulling force of several ten kilograms and work strength is medium. Each day the total exercise time is in the range of 60-90 minutes. According to results of investigations of astronauts after returning to earth, physical exercise was very effective in lightening the unhealthy effects of weightlessness. Besides this, the performing of exercise when there was negative pressure on the lower half of the body (-35 millimeters on the mercury column) each day in the air for 6 hours starting 5 days before returning to earth was very effective for raising the endurance of a person while returning to earth to overweightness and the earth's gravity.

## II. Selection, Training and Health Assurances

The regulating of an astronaut's food composition to eliminate water loss and decalcification caused by weightlessness is a health safeguard measure which has already been practically proven. An increase of potassium in food has a relatively good effect on maintaining body fluid equilibrium; sometimes the effect of an increase of calcium and phosphorous cannot compare to potassium but an increase of these three components in the food combined with appropriate exercise has proven to be effective in eliminating or greatly decreasing decalcification, water loss and

and body weight loss.

Because the reactions of individuals to weightlessness are very different, it is necessary to carry out physiological selection of astronauts beforehand. There are many methods of selection but one of the main ones is undergoing weightless flight in an aircraft.

Training prior to navigation also requires undergoing weightless flight in an aircraft. Besides this, training can also be done under simulated weightlessness by being submerged and floating in water.

In recent years, research results on some people have shown that carrying out exercise 3 times a day wherein the body lies level and the head is suspended 15° downwards and each time lasts 20 minutes can noticeably raise body endurance to weightlessness after entering outer space.

### III. Tentative Plans for Protective Equipment

Below we will introduce tentative plans for protection that have still not been practically applied.

#### 1. Pressurized Sleeves

In covering the arms, thighs and shanks with pressurized sleeves, we put pressurized gas into the sleeves and each minute or each specific amount of time gas is filled or placed in. Continuing in this manner promotes blood flow in the lower limbs and the muscles have rhythmic relaxation. This method has had

protective effects under ground simulated weightlessness yet the effects in space navigation are not ideal and its use is not convenient.

## 2. The Swaying Bed and the Negative Pressurized Suit

A patient who has laid in bed for a long time has clinically used a type of swaying bed. It is effective for the unhealthy reactions of laying in bed for a long time such as low blood pressure and dizziness. Yet, because its use is inconvenient there has not yet been agreement on its use in space navigation. However, in recent years, some people have used the principle of lower body negative pressure to make a protective suit and this has had protective results (chart 2-70).

## 3. Elastic Pressurized Suits

Some people have designed a type of whole body pressurized suit made from elastic fabric which allows the different parts of the whole body to sustain different amounts of pressure so as to simulate the load on different parts of the body's muscles and bones when a person is standing erect. However, tests conducted on persons lying in bed for 3 orbits did not show any protective effects of this type of pressurized suit. Moreover, the structure of the suit is complex and it is inconvenient and uncomfortable to wear. Yet, in recent years, some people have designed an elastic protective suit that produces pressure when the body moves and it has been said that it has protective effects against weightlessness (chart 2-71).



Chart 2-70 In this Negative Pressurized Suit Worn on the Lower Half of the Body, the Lower Half of the Body Forms Negative Pressure by Means of a Vacuum Method

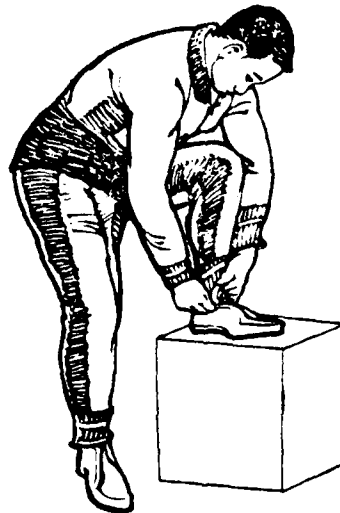


Chart 2-71 Elastic Protective Suit

#### 4. Artificial Gravity

The most ideal method for avoiding the effects of weightlessness is artificial gravity. This is a problem that can be considered for long term space observation stations. However, at present, many difficulties remain in this area of development and thus it has still not been realized. Yet, it is significant for further developments in space navigation.

There are two plans in the basic idea of artificial gravity. One plan is the use of continuous linear acceleration to produce artificial gravity. For example, when flying towards a certain celestial body, at the very beginning continuous acceleration is used for linear flight which causes the spaceship to produce gravity equal to 1 G. After flying halfway through the course there is then continuous deceleration which causes the spaceship to produce 1 G gravity in the opposite direction. At this time, the spaceship can turn over causing the artificial gravity to be equal to that of the human body in the head - foot direction. When the spaceship reaches its target, speed can be reduced to 0. Theoretically, this type of plan is ideal. Based on calculations, when a spaceship uses steady linear acceleration of 2 G and continuously flies for 24 hours, it can fly 72 million kilometers and the final speed reaches 6 million kilometers/hour. If there is half time acceleration flight, half time deceleration flight and a steady production of 2 G gravity, then it can fly to the moon in 3.5 hours and fly to Mars in 42 hours. However, at present,

there are still many difficulties in engineering technology for realizing this type of linear acceleration and it is not applicable for spaceships orbiting the earth.

Another design plan for artificial gravity has continuously been the center of discussion. It uses the centrifugal force produced from the turning of the aircraft to create artificial gravity. There are also several different ideas for this type of plan.

(1) The most common is the cannular space station as shown in chart 2-72.

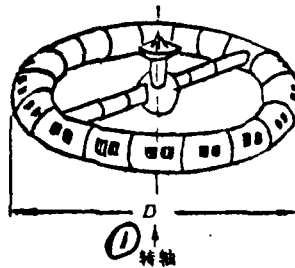


Chart 2-72 Picture of Cannular Space Station

In the chart, D is the diameter and the center vertical line is the rotating axis.

#### 1. Rotating axis

This type of space station resembles a large circular tube and the cannular body is the spaceship's cabin. When this type of space station turns around on its own cannular center, gravity is produced towards the circular tube's outer wall by the centrifugal force. When a person in the circular tube stands with their

feet facing the outer wall of the circular tube, the circular tube wall acts as the floor and the person feels as if he is standing on the earth's surface.

(2) Two spaceships are joined by a steel rope and the rope is tied around one common center of rotation as if a centrifuge with a two sided (or two ended) cabin. Artificial gravity is produced in the spaceship modules away from the rotating center by the centrifugal force.

Based on calculations, the cannular space station has a diameter of 12 meters, rotates at a speed of 6 cycles/minute and can attain 0.25 G artificial gravity. Space stations with diameters of 61 meters and which have rotating speeds of 5-6 cycles/minute can produce 0.1 G gravity.

The lowest limit of gravity needed for people to have normal movements and activity is about 0.3 G, yet in 0.14-0.16 G gravity people can manage movements and activities with great effort. Although from the point of view of engineering technology rotating artificial gravity is a satisfactory plan, unfortunately, in light of human physiology, there still exist many problems. For example:

(1) When people live in a rotating environment they have 1-2 days of non-adaptation. During this period, vestibulo-vegetative reactions such as vertigo and nausea as well as symptoms of motion sickness are difficult to avoid. Without a doubt, adaptation slowly comes later. However, when returning to earth there again appear symptoms of adaptation.



(2) In a rotating environment, visual illusions can be caused by rotation and thus result in space direction disorder.

(3) In a rotating artificial gravity environment, there will no doubt be various illusions and uncomfortable autonomic nerve reactions due to threshold acceleration.

In order to decrease these unhealthy physiological reactions produced by rotation to a level on which no serious effects on the human body will be produced, the rotating speed of the rotating artificial gravity station must be greatly limited.

In summary, the designs for rotating artificial gravity have still not reached a satisfactory level and therefore are not able to be accepted for use but await further research and investigation.

CHAPTER TEN  
NOISE AND SENSE OF HEARING

Section One    Preface

I. Noise is a Type of Environmental Pollution

Noise is a disturbing as well as a harmful factor to people. Due to advances in aviation, industry and communications, noise has become one of the environmental pollutions in cities. These problems are even more serious in industrialized capitalist nations. For example, taking the United States as an example, 80 million people are effected by noise. The effect of noise on children is especially worthy of serious attention. For example, a large city of mostly pedestrians with busy traffic sometimes has noise intensity which reaches 90-110 decibels<sup>F.N.1</sup>. Among the children living in this type of environment for a long time (for example, all day), about 40% will have permanent reduction in hearing.

It is worthy to note that in recent years city and industrial noise has gradually increased. According to reports, environmental noise has doubled every ten years in the United States. In the last

F.N. 1 A decibel is the unit of relative intensity for sound:

$$\text{Decibel value} = 10 \log \frac{\text{intensity of sound}}{\text{basic intensity}} = 20 \log \frac{\text{sound pressure}}{\text{basic standard sound pressure}}$$

Generally, the lowest sound audible to the human ear is used as the basic standard which is  $0.00002 \text{ newton/meter}^2$  or  $10^{-10} \text{ microwatts/centimeter}^2$ .

ten years, environmental noise in large cities in the Soviet Union has also increased 8-12 decibels. During the last several years, the number of people in the United States seeking compensation because of injuries to hearing has increased nine fold. Recently, an investigation in Sweden of youths applying for work indicated that about 20% of them had different degrees of hearing loss due to the effects of environmental noise and this was a two fold increase as compared to 1956.

Noise is also relatively serious in aviation and space navigation especially modernized aviation aircraft where noise intensity is very great. It not only effects pilots but also effect ground personnel and citizens living in the surrounding areas.

## II. Spaceship and Aircraft Noise

There are two categories of noise which are quite easily perceived in space navigation. One category is noise from the spaceship's power system which is mainly in wide frequency bands and in low frequency sections where sound pressure is high. The other category is aerodynamic noise produced from border eddies of air when a spaceship passes through dense atmosphere. This category of noise is also in a wide frequency band yet its high frequency section is dominant. These two categories of noise are produced when a spaceship is launched, ascends, returns and is in powered flight. See charts 2-73 to 2-75 for its intensity.

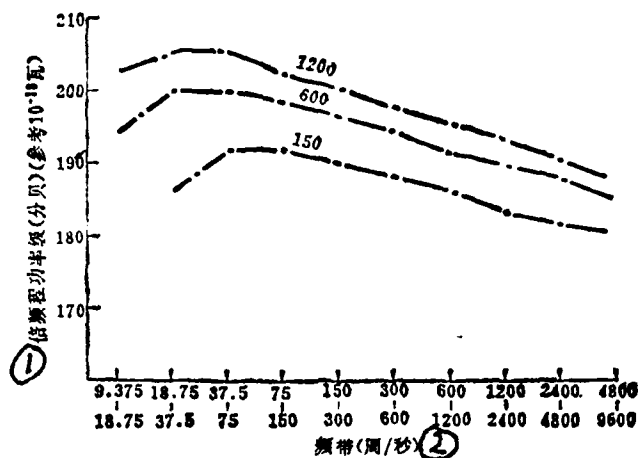


Chart 2-73 Estimated Noise of Different Rocket Thrusts

- The numbers on the curves indicate thrust (1,000 pounds)
1. Multiple frequency range power level (decibels), (refers to  $10^{-12}$  watts)
  2. Frequency band (cycles/second)

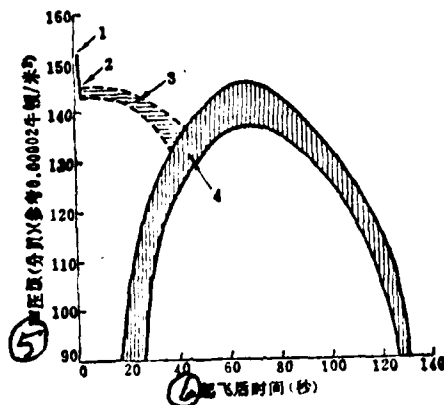


Chart 2-74 Noise (Estimated Value) at Different Times After Rocket is Launched (Powered Flight Stage)

1. Stationary time

2. Lift-off time
3. Greatest noise
4. Boundary area noise
5. Sound pressure level (refers to  $0.00002 \text{ newton/meter}^2$ )
6. Time after lift-off

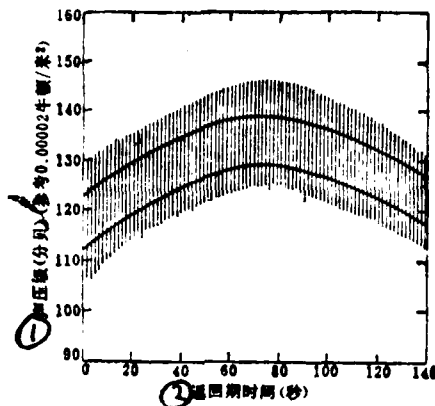


Chart 2-75 Noise on Boundary Layer Outside Spaceship Module During Return

1. Sound pressure level (refers to  $0.00002 \text{ newton/meter}^2$ )
2. Time during return (seconds)

Chart 2-76 also lists the noise changes of a spaceship during lift-off and return. For the most part, during the 120 second period when a spaceship is launched and lift-off, the total sound pressure of noise reaches its peak during the 60 seconds after lift-off. The sound pressure of the outside of the spaceship can reach 158 decibels and the sound pressure inside the spaceship module can reach 125 decibels. The sound pressure on the ears when an astronaut is wearing a helmet is 108 decibels. Sound pressure on the abdominal area inside a spacesuit is 120 decibels. Consideration of protection against noise during this period is especially needed. After a spaceship flies out of the dense atmospheric layer, because the

surroundings have no air to carry sound, therefore not only do the surroundings have no noise but it actually changes into cosmic stillness.

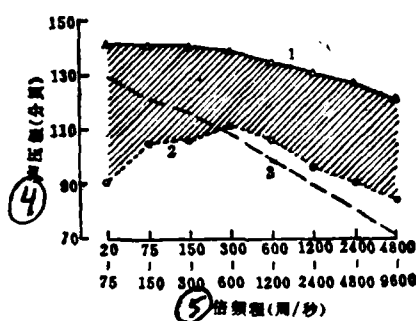


Chart 2-76 The Noise Inside and Outside of a Spaceship Module

1. Noise outside module
2. Noise inside module
3. Noise inside module calculated according to the law of mass
4. Sound pressure level (decibels)
5. Multiple frequency range (cycles/second)

For the general situation of aircraft noise see charts 2-77 and 2-78.

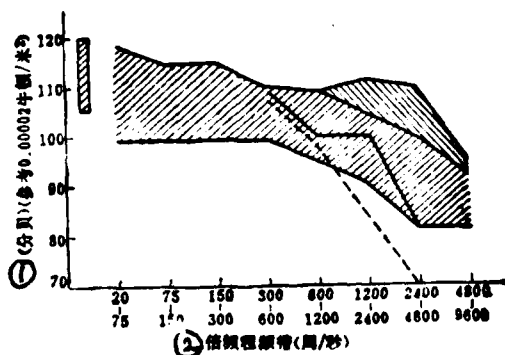


Chart 2-77 Helicopter Noise (the Different Curves Indicate Different Helicopters)

1. (Decibels), (refers to 0.00002 newton/meter<sup>2</sup>)
2. Multiple frequency range frequency band (cycles/second)

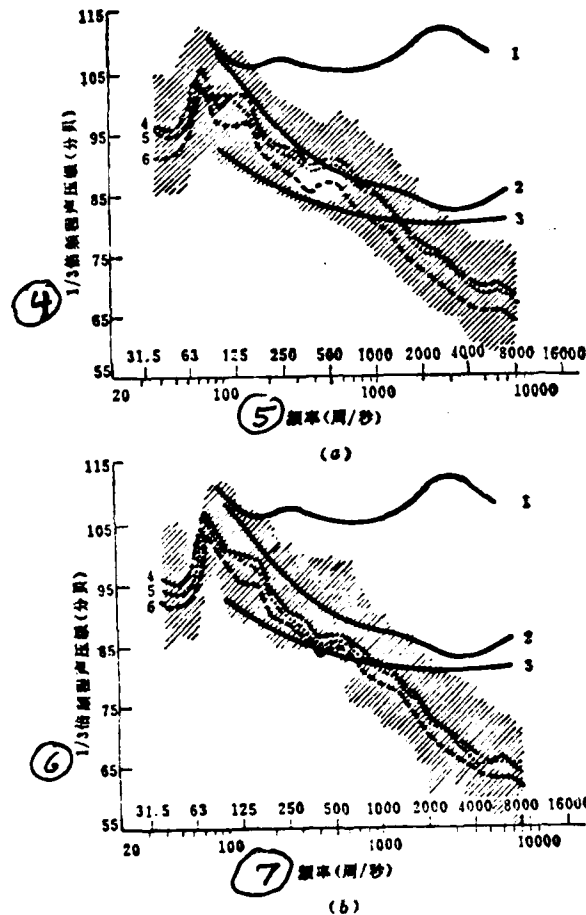
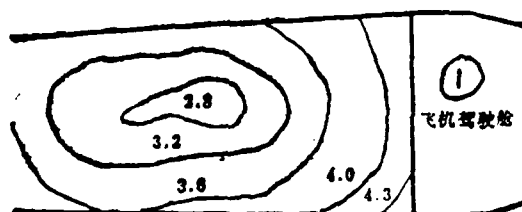


Chart 2-78 The Noise Inside the Cabin of a Common Single Engine Aircraft at Different Altitudes (Dotted Lines in Chart)

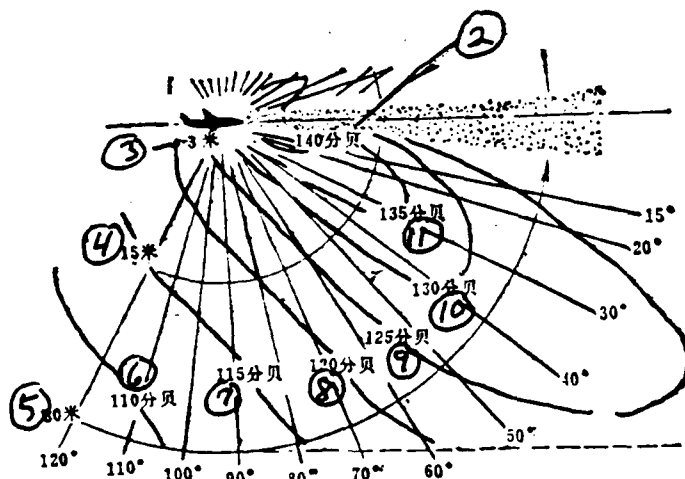
1. Using V51R model earplug protection gives a 480 minute safety limit
2. When no earplugs are used there is a 120 minute safety limit
3. When no earplugs are used there is a 480 minute safety limit
4. 1/3 multiple frequency range sound pressure level (decibels)
5. Frequency (cycles/second)
6. 1/3 multiple frequency range sound pressure level (decibels)
7. Frequency (cycles/second)

Chart 2-79 lists the noise changes and distribution of surrounding sound pressure in different places inside and outside of the aircraft cabin. (a) is the noise in different places inside a civil aviation aircraft passenger cabin (a piston engine aircraft). The numerical values in the chart are at a low sound pressure level (the unit is dyne/centimeter<sup>2</sup>). (b) is the noise field produced when a jet enters static air and the wave section in the chart is the equivalent sound intensity line.

These noises not only effect pilots, flight personnel and passengers but also do great harm to airfield workers and citizens living in the surrounding areas.



(a)



(b)

Chart 2-79 Noise of an Aircraft in Different Places

(Key-next page)



1. Aircraft control cabin
2. 140 decibels
3. 3 meters
4. 15 meters
5. 30 meters
6. 110 decibels
7. 115 decibels
8. 120 decibels
9. 125 decibels
10. 130 decibels
11. 135 decibels

## Section Two    The Harm of Noise to Hearing

Besides interference, noises under 60 decibels do not generally harm the human body but stronger noises can. Generally speaking, the harm of noises under 165 decibels are mainly to hearing and there is only temporary interference to other physiological activities; noises over 165 decibels create other injuries.

The harm of noise to hearing causes temporary or longer disruption of hearing and even permanent loss. The different lengths of time of harm to hearing can be divided into three categories:

1. Hearing Reduction for a Short Time (the Auditory Threshold Rises)

This type of phenomenon is called auditory fatigue<sup>F.N.1</sup> and it can gradually disappear and return to normal 1-2 days after the noise has stopped. The extent of hearing reduction and the length of recovery time are both related to noise intensity, exposure time and frequency range. For example, 12 seconds of exposure to 128 decibel noise is sufficient to reduce hearing 68 decibels for a

---

F.N. 1 Some people place auditory fatigue together with auditory threshold shift which will be discussed later and jointly call them auditory threshold shifts.

short time, more than 1 minute of exposure to 90-100 decibel noise can also noticeably reduce hearing, for 80-90 decibel noise to cause temporary hearing reduction 5 minutes of exposure is needed and 75-78 decibel noise requires several hours of exposure to cause a temporary reduction of 4-5 decibels. If the hearing reduction index is fixed relatively low then 1 minute of exposure to 60 decibel noise can create very slight hearing reduction. If the noise is not very intense and if exposure time is long, its harm can reach a relatively distinct level. For example, 8 hours of exposure to 74-76 decibel noise only causes 4-5 decibel hearing reduction but when exposure is continued for 30 days, this not only causes some people a 25-30 decibel hearing reduction but 2 days of recovery time is needed.

## 2. Temporary Auditory Threshold Shifts

This indicates hearing loss that requires several days to several months recovery time. Very intense noises that do not necessarily have long exposure times can possibly cause this type of harm. Jet aircraft noise of 110 decibels that lasts for 30 minutes at a distance of 4-5 meters can cause a person's hearing of high frequency sounds (above 1,000 cycles/second) to drop 30-65 decibels and hearing of low frequency sounds (128-512 cycles/second) to drop 5-10 decibels with a more than 6 day recovery period required. Lower intensity noises must have relatively long action time to be able to create this type of harm.

People's auditory threshold value have highs and lows in relation to sounds at different frequencies. Chart 2-80 shows the auditory thresholds of a normal youth and an old person. The audior,

threshold of the latter to high frequency is much higher than that of the former (the higher the auditory threshold the more defective the hearing).

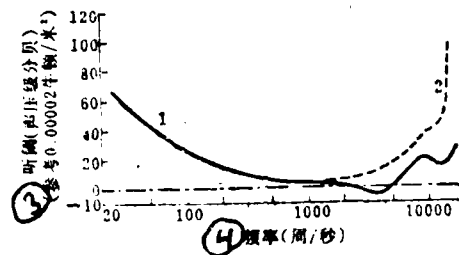


Chart 2-80 A Person's Auditory Threshold

1. Auditory threshold of normal 20 year old
2. Auditory threshold of a 60 year old
3. Auditory threshold (sound pressure level in decibels),  
(refers to 0.00002 newton/meter<sup>2</sup>)
4. Frequency (cycles/second)

An auditory shift indicates a phenomenon where the auditory threshold rises and 2 days to several months are needed for recovery. If recovery time is shorter than 2 days, then this belongs to the category of "auditory fatigue." Yet, there are also some people who jointly call the two auditory threshold shifts. If hearing can never recover, this is called "permanent hearing loss" or "hearing damage."

Temporary auditory threshold shifts have the following characteristics:

- (1) the auditory threshold rise can reach 35 decibels or more and high frequency section shifts are relatively large;
- (2) most people's auditory threshold shifts occur in the area

of 4,000-6,000 cycles/second and the auditory threshold of sounds at these frequencies have their largest rise;

(3) the auditory threshold shifts caused by most industrial noise are produced in the first 2 hours of exposure to the noise;

(4) when noise does not change, the auditory threshold shift is the same each day. When noise intensity increases, then auditory threshold shifts increase;

(5) the larger the auditory threshold shift, the longer the recovery time;

(6) the auditory threshold shift value measured 2 minutes after to exposure to noise can correspond to the permanent hearing damage caused by 10 years of industrial exposure to this type of noise.

For the intensity threshold values of "auditory threshold shifts" produced after less than 8 hours of continuous noise, see table 2-23.

① 噪声倍频程声压级 (分 贝)	② 2千周/秒 暂时阈移中数(分贝)						④ 3千周/秒 暂时阈移中数(分贝)						⑥ 4千周/秒 暂时阈移中数(分贝)						⑧ 6千周/秒 暂时阈移中数(分贝)					
	③ 暴露时间(分)						⑤ 暴露时间(分)						⑦ 暴露时间(分)						⑨ 暴露时间(分)					
	10	5	2	1	0.5	0.2	10	5	2	1	0.5	0.2	10	5	2	1	0.5	0.2	10	5	2	1	0.5	0.2
82	3	1					3	1					6	3					12	8	2			
87	6	4	2				7	4	2	1			11	7	3	1			17	12	4	1		
92	9	6	3	2			11	8	4	3	2		16	11	6	3	2		23	17	9	6	4	3
97	12	9	5	3	1		16	12	6	4	3	1	21	15	10	5	4	1	28	21	14	10	7	5
102	15	11	7	4	2		20	16	9	6	4	2	26	20	13	8	6	2	33	26	18	13	10	7
107		14	8	5	3	1		18	12	9	5	3		25	17	11	8	4		31	22	17	13	9
112			10	6	4	2			14	12	6	4			20	14	10	6			27	20	15	11
117				8	5	3				14	8	5				16	12	7				24	18	13
122					6	4					9	6					14	9					21	15

Table 2-23 Noise Intensity, Exposure Time and Temporary Threshold Shifts

(Key-next page)

1. Noise multiple frequency range sound pressure level
2. 2 kilocycles/second; number in temporary threshold shift (decibels)
3. Exposure time (minutes)
4. 3 kilocycles/second; number in temporary threshold shift (decibels)
5. Exposure time (minutes)
6. 4 kilocycles/second; number in temporary threshold shift (decibels)
7. Exposure time (minutes)
8. 6 kilocycles/second; number in temporary threshold shift (decibels)
9. Exposure time (minutes)

See table 2-24 for the relationship between the size of auditory threshold shifts and the length of recovery times. It can be seen from this table that the larger the auditory threshold shift the longer the recovery time.

① 阈移(分贝)	② 平均恢复时间
10	③ 8分
20	④ 1小时
30	⑤ 4小时
40	⑥ 30小时
50	⑦ 65小时

Table 2-24 The Relationship of Temporary Threshold Shifts and Mean Recovery Time

1. Threshold shift (decibels)
2. Mean recovery time
3. 8 minutes
4. 1 hour
5. 4 hours
6. 30 hours
7. 65 hours

### 3. Permanent Hearing Loss

The action time of more intense noise is relatively long and can cause permanent hearing loss. For example, 110-130 decibel noise

with 1 month exposure will cause noticeable permanent hearing loss. Repeated exposure to peak value intensity 140 decibel gun sounds on the battlefield can cause permanent hearing loss. 160 decibel noise can also cause perforation of the tympanic membrane and permanent hearing loss is often seen in exposure to occupational noise. Their hearing losses are mainly at frequencies above 24 cycles/second.

The course of exposure to industrial noise which causes permanent hearing loss is progressive. At first, it occurs for sounds in the 4,000 cycles/second range, then is extended to the 2,048-4,096 cycles/second range and finally loss develops towards the two ends; development in the high frequency section is relatively fast. Chart 2-81 is a schematic diagram of this course of development. In the chart, the 0 decibel horizontal line indicates normal hearing and curves 1,2,3 and 4 separately represent the different development stages of occupational deafness.

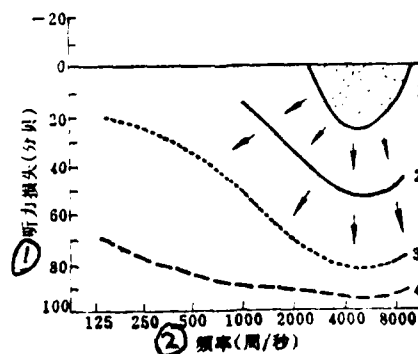


Chart 2-81 Schematic Chart of the Development Course of Occupational Deafness

1. Hearing loss (decibels)
2. Frequency (cycles/second)

Judging from the morphological changes of the auditory organs, the development of occupational deafness can be divided into three stages: in the first stage no harm to the hair cells in the inner ear cochlea is observed; in the second stage, the outer layer hair cells are completely lost, there is sustained tissue damage and there is also harm done to the inner layer hair cells; in the third stage, the auditory receptors are irreversibly and completely damaged. Because hearing loss in occupational deafness is progressive, most people do not become aware of it within a short period of time; they usually become aware of it when hearing loss of 500-2,000 cycles/second sounds reaches over 20 decibels. Then they use labor protection but by that time it is too late. Hearing aids can usually not be used to compensate for serious occupational hearing loss because the inner ear auditory receptors already have organic atrophy and damage so that they cannot be restored.

Permanent hearing loss caused by long term exposure to noise (including occupational exposure) possesses the following characteristics:

(1) The larger the total energy of the noise the shorter the time needed to cause permanent hearing loss.

(2) Hearing loss is mainly above 2,000 cycles/second and especially in the frequency spectrum of 4,000-6,000 cycles/second.

(3) One special feature of hearing loss is that when speaking in a loud voice to a person with hearing loss, he usually says: "Don't yell, I'm not deaf." In reality, however, even if one speaks loudly, he finds it difficult to hear clearly.

(4) The course of the development of permanent hearing loss is usually: after exposure to noise there is a relatively large shift of the auditory threshold. During a later period, hearing gradually recovers to a certain extent, yet a certain level of hearing (a specific frequency spectrum range) loss cannot be restored and this non-restorable part then becomes permanent hearing damage.

If after many years of working as a pilot or airfield worker with poor protection against noise some people sustain occupational hearing loss. Chart 2-82 shows the relationship of the flight times of civil aviation pilots and hearing loss. It can be seen from this chart that hearing loss is prolonged and increases according to flight time. When considering the problem of hearing loss caused by long time exposure to this type of occupational noise, it is also necessary to consider the influence of age because the hearing of an adult who has not been exposed to intense noise can also be prolonged according to age and be reduced to a certain extent.

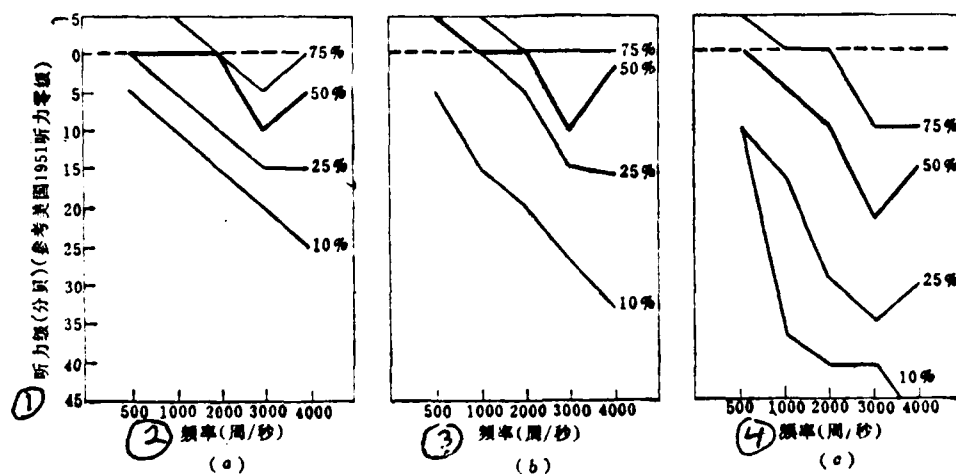


Chart 2-82 Harm to Pilot's Hearing With Different Flight Times

(Key-next page)



":" indicates the percentage of people in this type of audiogram with hearing deficiency. For example, the 50% curve is the mid-value of the audiogram which is indicated here by a thick line.

- (a) Flight time 1-2 thousand hours
- (b) Flight time 4-6 thousand hours
- (c) Flight time 10-16 thousand hours
- 1. Hearing level (decibels), (refers to the 1951 United States zero hearing level)
- 2. Frequency (cycles/second)
- 3. Frequency (cycles/second)
- 4. Frequency (cycles/second)

In table 2-25, the numbers in brackets in the first line indicate the number of people who have not yet been exposed to intense noise (greater than 80 decibels) and hearing declines in accordance with increase in age. The others separately show the percentage of people with serious hearing loss after a certain number of years of occupational exposure to different intensities of noise (the numerical values listed in the table have already deducted the percentage of people who have hearing reduction due to age). This table uses hearing losses greater than 25 decibels as the critical index of serious hearing damage. Because hearing loss is above 25 decibels, hearing of speech sounds is weakened which affects the ability of the sufferer to hear people speak. This table is applicable for continued occupational exposure to noise and the exposure time to continuous noise is determined according to a five day week, 8 hours each day. The data in this table are not applicable for exposure to pulsating noise (for example, few and scattered gun sounds). A certain conversion should be done for disconnected noise (for example, noises that occur several minutes to several hours apart) so that this table can be used after conversion to an equivalent of exposure

to continuous noise intensity.

		③ 噪声暴露年数									
① 噪声声压级 (分贝)	② 严重听力损伤的人数%	0	5	10	15	20	25	30	35	40	45
		0	0	0	0	0	0	0	0	0	0
<80 ● FN 2		(1)	(2)	(3)	(5)	(7)	(10)	(14)	(21)	(33)	(50)
85		0	1	3	5	6	7	8	9	10	7
90		0	1	10	14	16	18	18	20	21	15
95		0	7	17	24	28	29	31	32	29	23
100		0	12	29	37	42	43	44	44	41	33
105		0	18	42	53	58	60	62	61	54	41
110		0	26	55	71	78	78	77	72	62	45
115		0	30	71	83	87	84	81	75	64	47

FN1 ● 本表所称严重听力损伤是指500周/秒、1000周/秒、2000周/秒频率纯音的听阈上升25分贝以上。

FN2 ● 此行括号内值为由于年龄影响而造成的听力严重损伤的人数%。年龄以18岁为起点。因此，0年即表示18岁，45年即表示63岁，其余类推。

Table 2-25 Exposure to Continuous Occupational Noise - The Percentage of People with Serious Hearing Damage Created 8 Hours a Day, 5 days a week (The Numerical Values in the Table Have Already Deducted the Percentage of People with Serious Hearing Damage Due to Age)

1. Noise sound pressure level (decibels)
2. The percentage of people with serious hearing damage
3. The number of years of exposure to noise

F.N. 1 Serious hearing damage mentioned in this table points to pure sound auditory threshold rises over 25 decibels at 500 cycles/second, 1,000 cycles/second and 2,000 cycles/second frequencies.

F.N. 2 The values in brackets in this line are influenced by age and make up the percentage of people with serious hearing damage. 18 years is the starting point for age. Therefore, 0 years indicates 18 years of age and 45 years indicates 63 years of age.

### Section Three    Other Physiological Effects of Noise

Besides bringing about hearing damage, noise also causes certain disturbances and damage to the functioning of human organs, mainly in the following areas.

#### 1. Digestion and Nutrition

When a person resides in a noisy environment for a long period of time, the occurrence rate of ulcers and enterogastritis is relatively high. One reason for this is the inhibition of the normal activities of the stomach due to noise: 60 decibel noise can produce inhibitory action of the stomach, 80-90 decibels can cause stomach contractions to decrease 37% and 60 decibel noise can cause a 44% decrease in saliva secretion. Under the action of noise, the discharge of vitamin B<sub>1</sub> can rise. Vitamin B<sub>1</sub> in the heart, liver, kidneys and intestines decreases and is especially profound in the liver thus causing a vitamin B<sub>1</sub> deficiency.

#### 2. Respiratory System

Sudden action of noise over 90 decibels causes the respiration rate to rise. People who live in a noisy environment for a long time have slow and deep respiration and their incidence of asthma is relatively high.

#### 3. Cardiac Blood Vessel System

Sudden intense noise causes heart rate and blood pressure to drop. In 90-100 decibel low frequency noise, the heart rate slows down, the diastolic period is extended, peripheral blood vessels contract, arterial systolic pressure decreases and diastolic pressure rises. Blood pressure reactions to intense noise differ with each

individual; in some the pressure rises while for others it drops. Long term noise often causes the occurrence rate of cardiac blood vessel system illnesses to rise.

#### 4. Disturbance to Sleep

People easily fall asleep when there is weak and steady noise. On the contrary, intense noise and especially noise that comes suddenly causes disturbances to sleep. Under different degrees of noise there appear various interfering waves to a normal electroencephalogram of sleep and its amplitude increases in accordance with the loudness of the noise and thus shows a linear rise.

#### 5. Internal Secretion

Under the effect of noise there are increases in the adrenal cortex, marrow and thyroid gland secretion, the basic metabolism rate rises and the sex glands are inhibited. There are also corresponding changes in the biochemical composition of the blood.

#### 6. Nervous System

Continuous intense noise inhibits the central nervous system and sudden intense noise can even cause some sensitive people to faint. Long term residence in a noisy environment can cause an increase of slow waves in the electroencephalogram and a series of central symptoms such as fatigue, dizziness, a desire for sleep, a decrease in work efficiency, difficulty in concentration and poor memory. The occurrence rate of vestibular symptoms such as balance mechanism impairment and vestibular vegetative reactions also show increases.

## Section Four The Effects of Noise on Auditory Signals and Language Communication

Noise has a noticeable effect on auditory work efficiency. This is due to the covering action of noise on audible signals, and the largest actions are by those sounds which are close to its frequency. The most common frequency of sounds used in language communication are 500-2,000 cycles/second and therefore noise in this frequency spectrum is the largest interference to language. In order to raise the efficiency of auditory work signals in a noisy work area it is best to choose sounds that are relatively distant from the noise frequency as the auditory signals. Table 2-26 shows the dominant frequencies and intensities of several common auditory signals.

① 分 类	② 听 觉 信 号	③ 平均强度水平(分贝)		⑥ 主 宰 可 听 频 率 (周/秒)
		④ 距 离 3 米 处	⑤ 距 离 0.9 米 处	
⑦ 大 面 积 , 高 强 度	⑨ 10厘米铃	65~77	75~83	1000
	⑩ 15厘米铃	74~83	84~94	600
	⑪ 25厘米铃	85~90	95~100	300
	⑫ 喇叭	90~100	100~110	5000
	⑬ 汽笛	100~110	110~121	7000
⑧ 小 面 积 , 低 强 度	⑭ 高音蜂鸣器	50~60	70	200
	⑮ 轻声蜂鸣器	60~70	70~80	400~1000
	⑯ 2.5厘米铃声	60	70	1100
	⑰ 5厘米铃声	62	72	1000
	⑱ 7.5厘米铃声	63	73	650
	⑲ 铃声(哨音)	69	78	500~1000

F.N. 1 大面积高强度听觉信号在安静场所用50~60分贝强度, 在露天工场用70~80分贝, 在强噪声工厂、机器厂或冲压车间用90~100分贝。

Table 2-26 The Dominant Frequencies and Intensities of Several Commonly Used Auditory Signals (F.N. 1)

### 1. Category

2. Auditory signal
3. Mean intensity level (decibels)
4. Place at a distance of 3 meters
5. Place at a distance of 0.9 meters
6. Dominant audible frequency (cycles/second)
7. Large area, high intensity
8. Small area, low intensity
9. 10 centimeter bell
10. 15 centimeter bell
11. 25 centimeter bell
12. Horn
13. Siren
14. Heavy sounding buzzer
15. Light sounding buzzer
16. 2.5 centimeter bell sound
17. 5 centimeter bell sound
18. 7.5 centimeter bell sound
19. Bell sound

F.N. 1: Large area intense auditory signals use 50-60 decibel intensity in a quiet place, use 50-60 decibels in an open workshop and use 90-100 decibels in factories with intense noise, machine shops or stamping workshops.

The relation of auditory signals and noise intensity is often measured by the intensity ratio of the signals and noises and the unit measurement is decibels. The formula for calculating this is

$$S/N(\text{decibels}) = 10 \log S/N$$

In the formula,  $S/N$  is the signal-noise ratio (decibels),  $S$  is signal intensity and  $N$  is noise intensity. The smaller the signal-noise ratio the less understandable the language. Its general relationship is shown in chart 2-83.

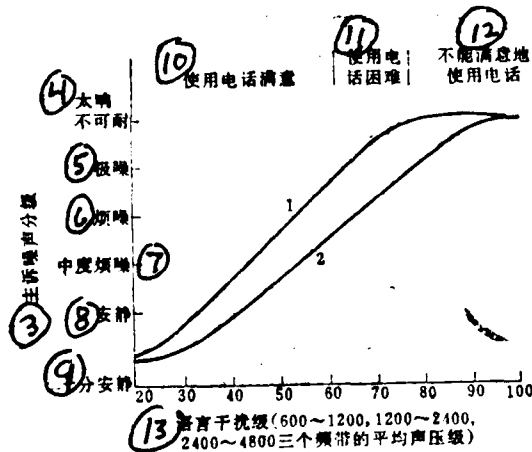


Chart 2-83 The Effects of Noise on Language Communication

- Line 1- The major complaints of listeners to normal speech spoken at a distance of 3 meters in a private office or conference room
- Line 2- The major complaints of listeners at a distance of 1 meter from a high voiced conversation in a secretary's, drawing, business or machine room
- 3. Major classifications of noises
- 4. Very noisy, unendurable
- 5. Maximum noise
- 6. Irritating noise
- 7. Medium irritating noise
- 8. Quiet
- 9. Totally quiet
- 10. Satisfactory use of telephone
- 11. Difficulty in using telephone
- 12. Not able to use telephone satisfactorily
- 13. Language interference level (mean sound pressure levels of 600-1,200, 1,200-2,400 and 2,400-4,800 frequency bands)

See charts 2-84 and 2-85 for the interference of language when the noise frequency bands are relatively wide and the intensities of each frequency component are more or less the same.

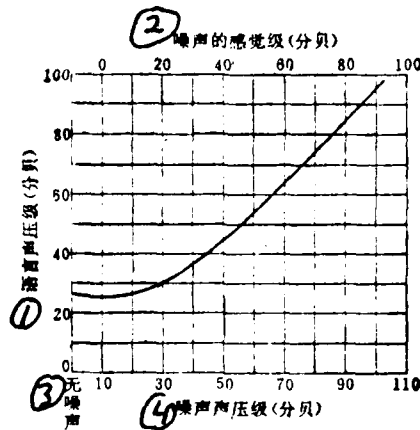


Chart 2-84 The Comprehension Threshold of Sentences During Continuous Speech Changes According to the Wide Frequency Band Noise Level

Here, the meaning of comprehension threshold is the language sound pressure level when the listener seems to be able to comprehend all of the sentences.

1. Language sound pressure level (decibels)
2. Noise sensation level (decibels)
3. No noise
4. Noise sound pressure level (decibels)

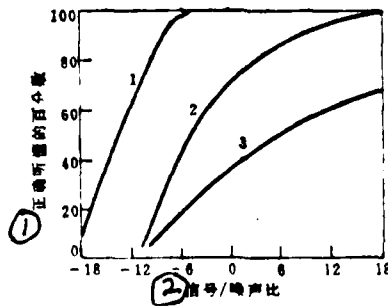


Chart 2-85 The Relationship Between Various Degrees of Comprehension and the Signal-Noise Ratio



The three curves in the chart measure the same communication system and use the same group of subjects.

1. Percent of accurate listening comprehension
2. Signal/noise ratio

The voice intensity commonly used by most people in telephone communications is in the 57-69 decibel range and if there is noise interference it is necessary to raise the voice to be able to effectively communicate. See chart 2-86 for the effects of different signal/noise ratios on language comprehension. "Voice level" is a measure for voice intensity.

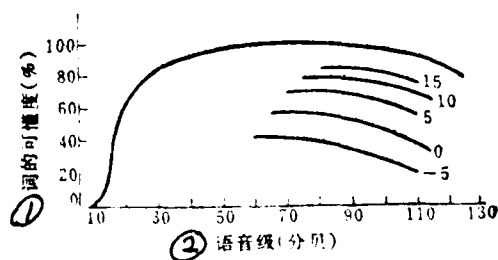


Chart 2-86 The Effects of the Signal-Noise Ratio on Language Communication

The highest curve is the degree of voice (words) comprehension heard in a quiet environment; each of the bottom lines separately indicates the voice comprehension in noisy environments with different signal-noise ratios - the numbers on each line indicate the signal-noise ratio.

1. Word comprehension (%)
2. Voice level (decibels)

Generally speaking, noise levels of less than 60 decibels do not affect telephone conversations. Noise levels that reach 60-75 decibels cause difficulty in telephone communications and when the level is greater than 75 decibels telephone communications are impossible. In order to guarantee effective oral communications when the noise is under 150 cycles/second and at a distance of 1.8 meters the noise cannot exceed 95-100 decibels and cannot exceed 85 decibels at 10,000 cycles/second.

The above effects all refer to continuous noise and in practice non-continuous noise is often encountered such as gun noise, exploding bomb noise and auditory signal noise. During intervals of disconnected noise there are also decreases in hearing. However, the effects of equal intensity noise are relatively small. The interference of relatively continuous noise on language is also small. In order to raise the efficiency of voice communications where there are disconnected noises, a method of repeated speech can be used.

#### Section Five    The Effects of Noise on Flight Capabilities

The general reactions of people to noise are feelings of monotony, anxiety and increased fatigue. Noises below 100 decibels have very little real effect on the efficiency of various types of non-auditory work. If noise above 100 decibels has not yet reached the auditory threshold (135-140 decibels), then it does not have a large effect on the efficiency of non-auditory work. However, sometimes 80-90 decibels intensity noise can affect precision monitoring work operations as well as relatively complex intellectual activities

requiring memory and discrimination. For the purpose of simplifying narration, we summed up the general circumstances of the effects of noise on work efficiency in table 2-27. The operations listed are all closely related to flight capabilities.

① 工作性质	② 工作情况	③ 噪声条件	④ 噪声强度 (分贝)	⑤ 对工作效率的影响
⑪ 用纯音作信号的警戒		②5 白噪声	112~115	③9 信号察觉效率与 $\sqrt{2 \times \text{信号/噪声}}$ 成正比关系
⑬ 钟面监视: 三个指针 一个指针		②6 白噪声	100	④0 信号脱离增多 ④1 未见明显影响
⑭ 20个仪表监督工作		②7 白噪声	100	④2 效率明显下降
⑮ 20个信号灯监督		②8 白噪声	100	④3 无明显影响
⑯ 示波器信号监视		②9 白噪声	73~93	④4 在信号间隔时间全距超过1分钟时影响明显
⑰ 三个灯闪现第10次的信号		③0 白噪声		④5 效率下降明显
⑱ 连续呈现的一系列图形中找标准符号		③1 白噪声		④6 效率下降明显
⑲ 000周/秒纯音信号反应时		③2 宽频带白噪声		④7 当信号/噪声比固定为30分贝时,反应时稳定,不随信号绝对强度而变化
⑳ 000周/秒纯音信号反应时		③3 纯音		④8 在信号/噪声比固定时,反应时随信号绝对强度的增大而增大
㉑ 宽频带白噪声信号的反应时		③4 宽频带白噪声		④9 反应时随信号绝对强度的增大而下降
㉒ 对五个信号灯作辨别反应		③5 高的噪声	80、90、100	⑤0 100分贝的噪声有不利影响,照明显则90分贝就有不利影响
㉓ 仪表读数 以及读数8小时,每2小时交替工作和休息		③6 白噪声	99	⑤1 无明显影响
㉔ 2分钟快速书写成对字母				⑤2 效率明显下降
㉕ 模拟雷达标图通信		③8 在电话中加入噪声		⑤3 工作效率随工作时间而快速下降

F.N. | ● 白噪声是指的各种频率都有,而且声压相等的噪声。

Table 2-27 The Effects of Noise on Work Efficiency

1. Characteristic of work
2. Work situation
3. Noise conditions
4. Noise intensity (decibels)
5. Effects on work efficiency
6. Warning monitoring work
7. Reaction times
8. Instrument reading
9. Writing
10. Charting communications
11. Use of pure sound for signal warning
12. Clock-face monitoring: three needles  
one needle

13. Monitoring tube work with 20 instruments
14. Monitoring tube with 20 signal lights
15. Oscilloscope signal monitoring
16. Signals with three lights flashing ten times
17. Seeking a standard symbol in a series of figures appearing continuously
18. Reaction time of 1,000 cycles/second pure sound signals
19. Reaction time of 1,000 cycles/second pure sound signals
20. Reaction time of wide frequency band white noise signals
21. Discrimination reaction of five signal lights
22. Instrument reading for 8 hours, every 2 hours change off work and rest
23. Quickly write alphabet letters in 42 minutes
24. Simulated charting communications
25. White noise
26. White noise
27. White noise
28. White noise
29. White noise
30. White noises appear disconnected
31. White noise
32. White noise
33. Wide frequency band white noise
34. Pure sound
35. Wide frequency band white noise
36. High noise
37. White noise
38. Noise enters telephone
39. The signal awareness efficiency and  $2 \times$  signal/noise ratio form a direct proportion relation
40. Signal missing increases
41. No noticeable effects
42. Noticeable drop in efficiency
43. No noticeable effects
44. Effects appear when the signal interval time for complete distance exceeds 1 minute
45. Noticeable drop in efficiency
46. Noticeable drop in efficiency
47. When the signal/noise ratio is fixed at 30 decibels, stable reaction time does not change according to the absolute intensity of the signals
48. When the signal/noise ratio is fixed, reaction time increases according to the increases of the absolute intensity of the signals
49. Reaction time drops in accordance with the increases of the absolute intensity of signals
50. 100 decibel noise has bad effects and when lighting is deficient 90 decibel noise has bad effects
51. No noticeable effects
52. Noticeable drop in efficiency
53. Work efficiency and speed drop in accordance with work time

F.N. 1 White noise exists at various frequencies and moreover is noise with equal sound pressure.

It should be pointed out that if noise causes shock or diverts attention, for example sudden intense or disconnected noises, when their intensity is low they can sometimes cause a decrease in work efficiency and their effect on complex intellectual activities, high degrees of attention and precision instrument reading is great.

#### Section Six    Endurance to Noise and Safety Limits

Man's endurance to noise is divided and separately discussed below according to the differences of their endurance indices.

##### 1. Ear Pain Threshold

Intense noise can cause pain in the ears which is called the auditory pain threshold. The auditory pain threshold is more or less at about 140 decibels. Yet, it differs in accordance with frequency as shown in chart 2-87. The reason why intense sounds cause ear pain is due to the excessive tension and vibrations of the tympanic membrane. For example, the tympanic membrane vibrations caused by 2,000 cycles/second pure sounds at 0 decibel intensity are only  $10^{-9}$  centimeters and at 140 decibel amplitude, vibrations can reach as high as  $10^{-2}$  centimeters. Noise over 160 decibels can cause tympanic membrane ruptures; ear pains are then portents of tympanic membrane injury.

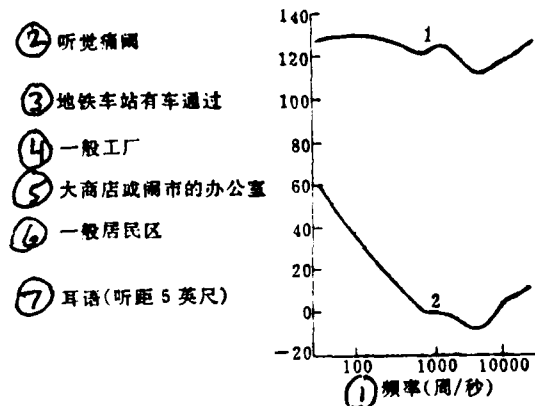


Chart 2-87 Auditory Pain Threshold (1), Auditory Threshold (2) and Different Environments of Noise

1. Frequency (cycles/second)
2. Auditory pain threshold
3. Train passes local railway station
4. Common factory
5. A large store or office in a city
6. Common residential area
7. A whisper (heard from a distance of 5 feet)

## 2. Hearing Damage Threshold

This uses hearing damage as the critical index. Based on this index, man's endurance time to audible frequency range noise intensity of 135 decibels is less than 10 seconds, endurance time to 125 decibels is 2 minutes and for 100 decibels it is 8 hours. During even longer exposure, endurance to noise frequency below 300 cycles/second does not exceed 90 decibels. Exposure of 1-2 months to 85 decibel noise generally does not cause permanent hearing damage yet when there is continuous exposure for over one year, there is the

danger of permanent hearing loss. It is safe to say that the limit of permanent hearing damage caused by long exposure is less than 85 decibels.

### 3. Discomfort Threshold

Noise causes the human body's discomfort physiological reaction threshold value to be 125-226 decibels with 20 minutes exposure. The subjective and objective manifestations of discomfort when the auditory threshold rises 10-15 decibels are headaches, clogged ears, decreases in pulse, rises in blood pressure, extensions of visual reaction time, and vibrating feelings in the limbs and abdominal area. Chart 2-88 is an example of how noise in an aircraft cabin effects the physiological discomfort reaction threshold value.

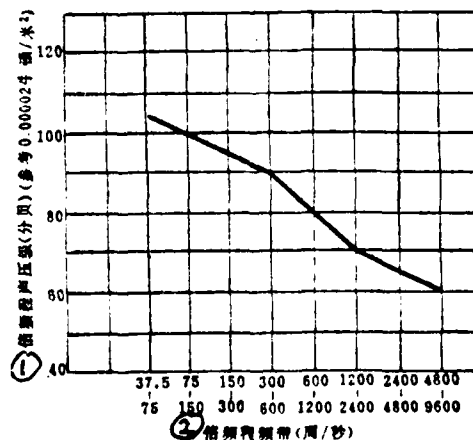


Chart 2-88 Major Discomfort Limitations of Noise in an Aircraft Cabin

1. Multiple frequency range sound pressure level (decibels)-

(refers to  $0.00002 \text{ newton/meter}^2$ )

2. Multiple frequency range frequency band (cycles/second)

#### 4. Safety Standards

International conferences have determined the safety protection standards to noise as: in an environment of noise for 8 hours each day noise should not exceed 90 decibels and modulated noise should not exceed 85 decibels.

Some people recommend that the permissible noise level in aircraft and spaceship cabins should not exceed 40 decibels. They considered the possibility of taking turns resting in a spaceship cabin and therefore proposed that during powerless flight, noise in the spaceship cabin should not exceed 35-40 decibels during daylight hours and should not exceed 25-30 decibels at night. This is beneficial to conversations, rest and sleep. Naturally, during takeoff and return the permissible level of noise must be relaxed for a short period of time because it is impossible at this time to cause noise to decrease to a level of powerless flight.

Charts 2-89 and 2-90 and table 2-28 sum up the data on noise safety standards and endurance.



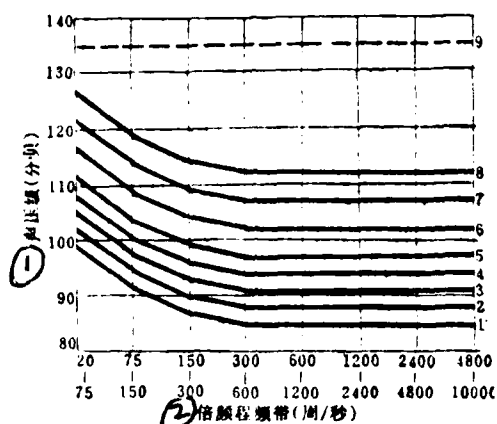


Chart 2-89 Permissible Limit to Long Term Occupational Exposure to Noise

In the chart, lines 1-8 separately represent exposure each day of 8 hours, 4 hours, 2 hours, 1 hour, 30 minutes, 10 minutes and 1 minute; line 9, composed of dashes, represents the highest total sound pressure level permissible to the ear during a single exposure.

1. Sound pressure level (decibels )
2. Multiple frequency range frequency band (cycles/second)

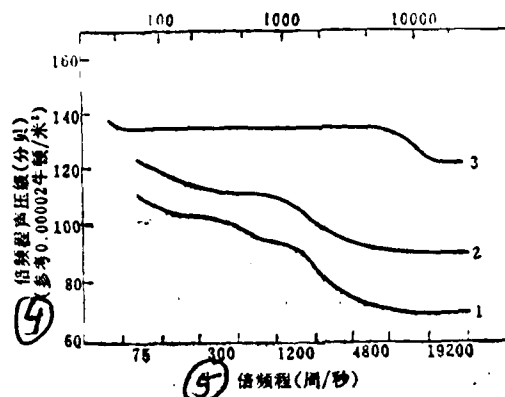


Chart 2-90 Recommended Noise Limit in Spaceships

- Line 1. Demanded noise sound pressure level
- Line 2. Highest permissible noise sound level
- Line 3. Auditory pains, fatigue and headaches; operation efficiency seriously drops; long term exposure causes auditory damage
- 4. Multiple frequency range sound pressure level (decibels)-(refers to  $0.00002 \text{ newton/meter}^2$ )
- 5. Multiple frequency range (cycles/second)

① 噪声声压级(分贝)	② 防护条件	③ 最大许可时间
108	④ 没有耳朵防护	⑥ 1小时
120		⑦ 5分钟
130		⑧ 30秒
135		⑨ 10秒或更短
112	⑤ 有耳朵防护	⑩ 8小时
120		⑪ 1小时
122		⑫ 5分钟
142		⑬ 30秒
147		⑭ 10秒

Table 2-28 Longest Permissible Time of Exposure to Noise

1. Noise sound pressure level (decibels)
2. Protection conditions
3. Longest permissible time
4. Without ear protection
5. With ear protection
6. 1 hour
7. 5 minutes
8. 30 seconds
9. 10 seconds or less
10. 8 hours
11. 1 hour
12. 5 minutes
13. 30 seconds
14. 10 seconds

## Section Seven Protection Against Noise

### 1. Technical Protection Against Weak Noise Sources

To decrease noise sources and the noise intensity produced by them or to increase the distance between the noise source and people are very important technical measures for protection against noise. Means to decrease noise intensity should be taken as far as possible in the design of aircraft and spaceship.

## 2. Sound Insulation and Sound Absorption

The use of sound insulation and sound absorption equipment in aircraft and spaceship cabins as well as in various structures are very effective types of protective measures against noise.

## 3. Earplugs and Semi-Earplugs

Earplugs are a relatively good protective means for worksite, inside cabin and room noise. Earplugs can obstruct the hearing of language when there is no noise. However, in noisy environments, well designed earplugs not only do not effect language communication but can raise to a certain degree language discrimination when there is noise. In order to not obstruct telephone communications, a type of earplug with an earphone can be used (resembling an earphone in a hearing aid) which is called an "ear cover" or "semi-earplug". Ear covers can possess the sound insulation effects of earplugs and will not obstruct the earphone's ability to relate messages. There is one danger in using earplugs in aviation. After an aircraft enters a high altitude the surrounding air pressure decreases considerably causing a relatively large pressure gradient inside and outside the ear with the earplug. If the earplug is suddenly taken away, this can cause a rupture in the tympanic membrane. In order to prevent this danger from occurring, a very small valve type slit can be made beforehand in earplugs used in aviation. This type of earplug can eliminate excessive differences in pressure on the

inside and outside of the ear and will not effect sound insulation. However, ear covers are generally used in aircraft and spaceships. Perfect sound insulation ear covers can decrease noise 20-30 decibels.

#### 4. Training For Noise

Adaptation can occur after multiple or long time exposure to noise. However, there is a certain amount of danger in undergoing training as a protective means of reaching adaptation because hearing loss often occurs at the same time as adaptation. Because of this, it is not beneficial to train against intense noise. However, training can be used to raise communication capabilities against disturbed speech communications and noise that does not cause harm to hearing. This has already been used to a large extent in military communications and it can also be applied in aircraft and spaceships.

#### 5. Preparation Noise

Several hundred microseconds before an intense noise occurs there is a relatively intense preparatory noise which does not cause harm and activation of the muscles in the inner ear, compensation reactions in the human body and tension in the ear bones can decrease the harmful effect of intense noise. When these types of devices are installed on big guns, protection effects equaling a 30-40 decibel decrease in noise intensity can be obtained.

#### 6. Simulated Cranial Sounds

People commonly use the difference in sound in the two ears

to discriminate the location of sounds because the time and intensity for sounds in different locations reaching the left and right ears is different. Based on this difference, people can differentiate the place of origins of sounds. The interference of sounds in different locations is smaller than sounds in the same location. Some people designed a method using audio amplifiers to carry out language communications. This method uses two audio amplifying forms arranged on the front part of the head, 30° on the left side and 30° on the right side. The two forms simultaneously transmit similar speech signals wherein they complement and oppose each other. When this is heard, a person feels that the speech is being emitted from inside the head and is different from any outside sounds. Thus, this type of speech is more easily distinguished than any sounds coming from the outside and furthermore there is less noise interference. According to test results, the use of this type of method for speech communications can cause speech comprehensibility when the signal/noise ratio is 0 decibels and  $\pm$  5 decibels to rise 12-14% and a raise of about 35% when the signal/noise ratio is -10 decibels. The auditory results caused by this type of audio amplifier resembles the sounds produced in the cranium and therefore some people call them "simulated cranial sounds".

#### Section Eight    The Roaring Sounds of Supersonic Aircraft

When supersonic aircraft fly by, people on the ground feel a tremendous noise like the sound of a bomb falling and this is

\*  
called a "roaring sound" or "sound wave explosion". This type of sound is not only produced when an aircraft breaks the sound barrier but is also continually produced in the places on the ground passed during aircraft supersonic flight. The reason for the production of a roaring sound is that when a supersonic aircraft flies passed in the air, pressure waves are formed which radiate out from the aircraft in all directions according to the velocity of sound. When an aircraft's speed is faster than the velocity of sound, pressure waves amass and form shock waves. Shock waves revolve around the aircraft, are dragged behind the aircraft and form a cone shape (see chart 2-91).

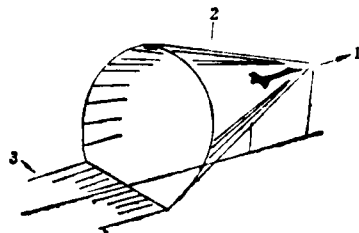


Chart 2-91 The Distribution of Aircraft Roaring Sounds (Also Called Sound Wave Explosions)

1. Aircraft course
2. Figure of roaring sound pressure distribution (a cone)
3. Distribution range of roaring sound on the ground

When the shock waves come in contact with the ground a roaring sound is produced. The intensity of the roaring sound depends on many factors such as the length, weight, flight altitude, speed and the angle of the flight path of an aircraft. Generally speaking, the higher the flight altitude the lower the intensity of the roaring sound and the wider the range occupied

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\* Read-sonic boom

by the sound. According to statistics, when the flight speed of a large transporter reaches 3 M (M is the velocity of sound), continuous flight at an altitude of 22,500 meters, there can be produced on the ground along the flight line a 5-7.5 kilograms/meter<sup>2</sup> peak value sound pressure roaring sound. If aircraft weight is relatively great and altitude is relatively low the peak value sound pressure can approach 10 kilograms/meter<sup>2</sup> which is close to the human auditory pain threshold. When modern supersonic aircraft fly at a cruise altitude and its flight path is in a 20 kilometer range, almost 98% of the ground pressure reaches 7.5-10 kilograms/meter<sup>2</sup> and the other 2% of the ground area's sound pressure is greater than 20 or less than 5 kilograms/meter<sup>2</sup>. This type of intense sound carries a certain amount of danger for people. However, the results of investigations have still not found cases of harm to the human body by this roaring sound. This is because the action time of the roaring sound is very short and is not sufficient to cause harm to the human body. However, it can interrupt work, conversations, television watching, radio listening, cause a person to be startled and agitated as well as disturb sleep.

As regards protection against roaring sounds, prior to the use of protective technical measures to prevent roaring sounds, people could only limit the flight altitude of supersonic aircraft. For example, one effective protective measure was setting an aircraft's flight altitude no lower than 9 kilometers. Flight design requirements should stipulate that roaring sound pressure not



exceed 10 kilograms/meter<sup>2</sup> so as to guarantee safety. For the general situation of aircraft roaring sound pressure and the harm threshold of the human body, see table 2-29.

① 项 目	② 千公斤/米 <sup>2</sup>	③ 达因/厘米 <sup>2</sup>
④ 估计人的肺损害阈 (峰值声压)	10.3	$1.033 \times 10^6$
⑤ 估计人的耳鼓膜损害阈 (峰值声压)	3.5	$3.455 \times 10^5$
⑥ 飞机飞行最低高度上, 地面所得的轰鸣声压 (对人无伤害, 但可能引起耳痛)	0.1~0.6	$9.571 \times 10^3 \sim 5.742 \times 10^4$
⑦ 飞机正常操纵高度上, 地面测定的轰鸣声压 (典型的航空交通条件)	0.024~0.24 ⑧ (很少>0.01)	239~2392 ⑨ (很少超过957)

Table 2-29 The Roaring Sound of Supersonic Aircraft and the Harm Threshold of the Human Body (Sound Pressure)

1. Item
2. 1,000 kilograms/meter<sup>2</sup>
3. Dyne/centimeter<sup>2</sup>
4. Estimated pulmonary damage threshold (peak value of sound pressure)
5. Estimated tympanic membrane damage threshold (peak value of sound pressure)
6. The roaring sound attained on the ground when an aircraft flies at the lowest altitude (no harm to man but ear pains are possible)
7. The roaring sound measured on the ground when an aircraft is at a normal operating altitude (typical aviation traffic conditions)
8. (Very rarely greater than 0.01)
9. (Very rarely exceeds 957)

## PART III ATMOSPHERIC ENVIRONMENT MEDICINE

### INTRODUCTION

Human beings cannot survive without air. The atmosphere we live in is a mixture of various kinds of gases. Each gas exerts its own pressure in proportion to the percentage of its occurrence in the total volume of the air, and also the total air pressure. The total air pressure equals the sum of all of the partial pressures. Since the composition of air varies insignificantly from ground to high altitude, the partial pressure of individual elements mainly depends on the total air pressure.

Nitrogen, comprising more than  $3/4$  of the air, has no direct relation to maintaining lives, but oxygen, comprising more than  $1/5$  of the air, is essential for human metabolism. Since human beings have lived constantly under normal air pressure and composition for a long period of time, they can only adapt to a small degree of change of partial oxygen pressure, either higher or lower. Exceeding the limit will cause some harmful effects. The reduced total air pressure due to increase in altitude will result in lower oxygen pressure. The higher the altitude is, the lower the total air pressure. Therefore, a human being has to be kept in a man-made environment of constant air and oxygen pressure while travelling at high altitudes. Not only excessively low oxygen pressure will cause harmful results; overly high oxygen pressure is detrimental to human health, namely, oxygen poisoning, as well. Although excessive total air pressure is harmful, its rare occurrence has not caused a problem to us yet. However, the rapid drop of air pressure will cause caisson disease, even decompression explosion, which has been a serious problem in aeromedicine.

The studies of the atmospheric environment in aeromedicine can be summarized into four different directions: low-air-pressure anoxia, oxygen poisoning, caisson disease, and the danger of decompression explosion. These problems will be extensively discussed in this chapter. Since air pollution is more related to ecology, it will be discussed in chapter 6.

## Chapter 11 The Physiological Effect of low-air-pressure anoxia

### I. Basic Concepts of Low-pressure Anoxia

The low-air-pressure anoxia discussed in this chapter refers only to excessively low oxygen pressure due to extremely low air pressure, not due to insufficient oxygen content in the respiratory air. Anoxia can be simulated in the laboratory by decreasing the oxygen content of the respiratory air and also in a closed cabin with low oxygen content. However, according to the physiological mechanism of anoxia, the preceding factors (low partial pressure and low oxygen content) are both categorized as environmental causes of anoxia. Naturally, anoxia can be caused by many other factors, namely, anemia, the malfunction of oxygenation of hemoglobin (in case of the presence of carbamino hemoglobin and ferrihemoglobin), histotoxication (e.g. by cyanic acid), respiratory or circulatory function impairment, which will not be discussed in this chapter. The discussion in this chapter will be only limited to the physiological study of anoxia caused by low air pressure. Anoxia caused by low partial pressure of oxygen is called anaerobic anoxia.

On the surface of the earth at sea level, the oxygen content of the atmosphere is 20.9%, and its partial pressure

is 159 mm Hg. The density of air drops according to the increase in elevation. The more the atmospheric pressure drops, the lower the partial pressure of oxygen is. The relationship between atmospheric pressure, air density and elevation is shown in Figure 3-1.

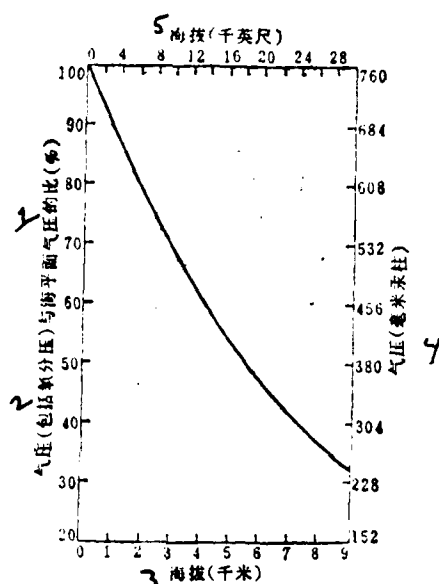


Figure 3-1. The correlation between elevation and atmospheric pressure (also applicable to  $O_2$  partial pressure).

Key: 1 - atmospheric pressure (including  $O_2$  partial pressure, 2 - atmospheric pressure at sea level, 2 - elevation (in 1000 m), 4 - atmospheric pressure (mm Hg), 5 - elevation (in 1000 ft.)

Anoxia will usually cause changes in electroencephalograms and mild vision disturbances when people stay above an altitude of 2000 m. The symptoms of anoxia become obvious for people staying at altitudes above 3000-4000 m. At an altitude above 4000-5000 m, the supply of oxygen is essential for the safety of newcomers and the efficiency of their work. At the altitude above 7000-8000 m, most people will show abnormal physiological reactions without a supply of oxygen. At

elevations above 9000 m, most of people will be threatened by death if no supply of oxygen is provided. The elevation of 10,000 m is probably the highest altitude people can survive without the supply of oxygen (including those people who are adapted to high altitudes). At an altitude above 12,000m, pure oxygen has to be provided in order to meet the need of histological respiration, since atmospheric pressure at that elevation is detrimentally low. At an altitude of 13,000m, the provision of oxygen will not relieve serious symptoms of anoxia. Under this circumstance, compressed pure oxygen has to be provided in order to meet the physiological needs. At an elevation above 10,000m, a closed cabin (or closed outfit, helmet) is necessary for the safety of human beings. At this altitude, the atmospheric pressure inside the closed cabin can be maintained by compressing the air around it into the cabin, which is also referred to as ventilatory or compressed closed cabin. While flying at an altitude over 21,000-24,000m, compressing the surrounding air into the cabin to keep a comfortable pressure will cause an overload of the equipment and elevation of cabin temperature, which results in unbearable high temperatures. Besides, it is not economical. Therefore, the airplane cabin has to be completely isolated from its surrounding, and its atmospheric pressure and content have to be maintained by artificial supply of oxygen.

## II. Gas Exchange and Transport in the Human Body

The activities of human beings depend on the oxidation process. Therefore, the inhalation of oxygen and exhalation of carbon dioxide can guarantee smooth physiological activities in the human body. In order to fully understand the mechanism of  $O_2$ -inhalation and  $CO_2$  - exhalation, it is necessary to review the human physiology of gas exchange and gas transport.

For human beings, gas exchange occurs in the lungs. Respiration is just a process to refresh continuously the gas in the lungs. We inhale  $O_2$  from the atmosphere, and exhale  $CO_2$  out into the atmosphere. The nitrogen and other gases in the atmosphere do not have any significant physiological function, but, like  $O_2$ , they are also absorbed into the blood and tissues, carried to the lung by blood and exhaled from there. The exchange of gas takes place mainly at the pulmonary alveolus, which is composed of 2 layers of thin walls and the abundant capillaries between them. There are approximately several million alveoli in the human lungs. The total cross sectional area of the alveoli approximates  $100\text{ m}^2$ , which shows us how big the area of air exchange can be. The structures of alveolus and respiratory passage and air exchange route are shown in Figure 3-2.

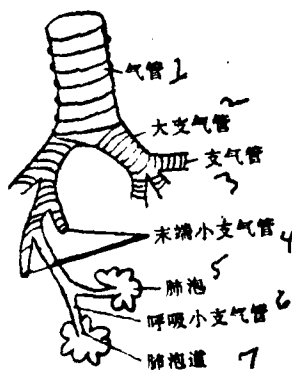


Figure 3-2. The structure of air passage and alveolus.  
Key: 1. trachea, 2. bronchus, 3. bronchiole, 4. terminal bronchiole, 5. pulmonary alveolus, 6. alveolar bronchiole, 7. alveolar duct.

A schematic diagram (Figure 3-3) shows the exchange of  $O_2$  and  $CO_2$  in the pulmonary alveolus. Oxygen diffuses into the blood as it passes through the alveolus, and  $CO_2$ , in the opposite direction, is released from the blood, and into the alveolar wall, then air sac. Due to this mechanical function, the alveolus exchanges the air with the atmosphere surrounding the body, namely, inhaling fresh air and exhaling dirty air.

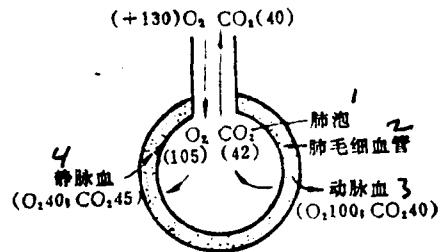


Figure 3-3. A schematic diagram of air exchange in pulmonary anveolus: the figures in the parentheses indicate the partial pressure.  $O_2$  - oxygen  $CO_2$  - carbon dioxide.

Key: 1. pulmonary alveolus, 2. pulmonary capillary, 3. oxygenated blood, 4. deoxygenated blood.

The basic gas law also applies to gas exchange in the human body. It simply says that any gas will diffuse from a high partial pressure to a low partial pressure area until equilibrium is reached. On the surface of the earth at sea level, the partial pressure of oxygen is 159 mm Hg. The partial pressures of  $O_2$  and  $CO_2$  in a pulmonary alveolus average from 103 to 105 mm Hg, and 40 to 42 mm Hg, respectively. The  $O_2$  partial pressure in arterial blood is close to that of the alveolus. The  $O_2$  and  $CO_2$  partial pressures in venous blood are 35-45 mm Hg and 42-45 mm Hg, respectively. The occurrence of lower  $O_2$  pressure and higher  $CO_2$  pressure in venous blood

is due to the fact that the  $O_2$  is used up by all the tissues and  $CO_2$  is released into the venous blood from the tissues. The basic diffusion law and our data of partial pressures can easily explain why the  $O_2$  will diffuse into venous blood and  $CO_2$  will be released into the alveolus. The arterial blood, saturated with  $O_2$  and depleted of  $CO_2$ , will circulate from the lungs through the whole body, then back to the left atrium. Although there is only a minor difference in the  $CO_2$  partial pressure between venous blood and pulmonary alveolus, the diffusion rate of  $CO_2$  is approximately 30 times that of  $O_2$ . Therefore,  $CO_2$  can be released, in time, from venous blood into pulmonary alveolus.

After oxygen diffuses into blood, it circulates with the blood through the whole body. There are two ways of transporting oxygen. Oxygen can either dissolve directly into the blood or combine loosely with the hemoglobin in the blood. The former, physical dissolution, plays a minor role in  $O_2$  transport. Most of the oxygen will combine chemically with hemoglobin to form oxyhemoglobin. The tissue metabolism keeps on consuming  $O_2$ . Therefore, the  $O_2$  partial pressure in the tissues is always lower than that in the arterial blood, which causes  $O_2$  to leave oxyhemoglobin and diffuse into tissues. After releasing the  $O_2$  (reduction), the oxyhemoglobin becomes ferro-hemoglobin which is ready for transport. The oxidation and reduction of hemoglobin depends on the concentration difference of  $O_2$  in blood and tissues, and also sometimes the acidity of blood (Figure 3-4). The degree of  $O_2$  saturation in arterial blood refers to the ratio of oxyhemoglobin to the total hemoglobin in the blood, which is an indicator of the extent of oxidation of hemoglobin, namely the degree of  $O_2$  saturation in arterial blood. It can be found in Figure 3-4 that the degree of  $O_2$  saturation of hemoglobin at altitudes below 2,500 m ( $O_2$  partial pressure in pulmonary alveolus is



higher than 65 mm Hg) is greater than 90%, which will not affect human health. However, the degree of  $O_2$  saturation of hemoglobin will drop drastically as the  $O_2$  partial pressure in alveoli drops below 60 mm Hg. Therefore, at altitudes above 2,500m, the symptoms of anoxia will become apparent and severe as the elevation increases.

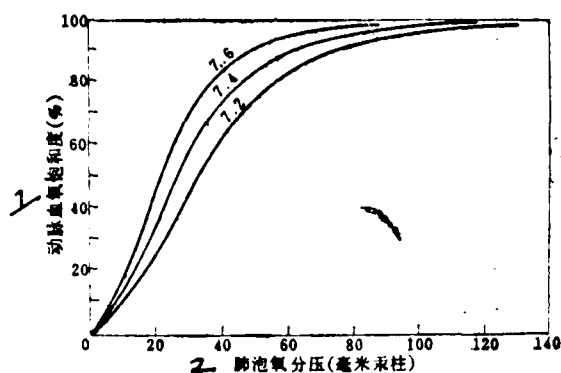


Figure 3-4. The effect of blood acidity on the  $O_2$  saturation of the arterial blood.

Key: 1. the degree of  $O_2$  saturation in arterial blood,  
2.  $O_2$  partial pressure in pulmonary alveoli (mm Hg)

### III The Physiological Effect of Anoxia

#### A. Major Symptoms

At an altitude above 300m, fatigue easily appears, but night vision may be improved. After a longer period of stay, some individuals will have headaches and fatigue as symptoms. At this elevation, most of the people will suffer mild discomfort. At the altitude above 4000m, the symptoms of anoxia

will become more significant. Shortness of breath and strength will appear while exercising, and over-excitment, talkativeness and impulsiveness will appear while resting. Some individuals will show symptoms of purple lips, unusual chill, mild headache, nagging, uneasiness, loss of appetite, nausea, vomiting, pressure in the chest, loss of muscle strength, melancholy. With higher elevation, more serious symptoms will develop until fainting or losing consciousness: feeling of heavy head, trembling temples, blurred vision, retrogress in hearing, inefficiency of work, feeling of heavy limbs, trembling, cramps, dizziness. If no emergency treatment is carried out, the patients' lives may be in danger. Table 3-1 lists the acute symptoms of anoxia at various elevations among individuals who are not adapted to high altitude. It can be concluded from Table 3-1 that it is safe, averagely speaking, under 2599 m; symptoms of anoxia become more significant above 3000m; severe symptoms of anoxia will appear above 6000-7000m; mortality will occur above 7500m.

TABLE 3-1 The correlation between elevation and acute anoxia symptoms among individuals who are not adapted to high altitude

Elevation (above sea level, 1000m)	Symptoms
1.5	Normal, but fatigue after a period of time.
1.5 - 2.4	No significant reactions within 30 min, but headache, fatigue appear if the stay is longer.
2.4 - 3.3	Significant change in sensation and reflex response after 1 hr., and headache and fatigue appear if the stay is longer.

TABLE 3 (Continued)

Elevation (above sea level, 1000m)	Symptoms
3.3 - 6.0	Significant physiological impairment after 15 min., esp. above 5000m; Fatigue, headache, dizziness, vision disturbance, loss of judging ability, impairment in coordination, increased pulse and respiratory rate, and purple lips appear as early symptoms. The symptoms will be aggravated if the stay is longer.
6 - 7.5	All the preceding symptoms develop drastically, and reach their serious stages in 3 - 10 min.
7.5 - 9.0	Acute shock appears in 3 min. Death occurs if the stay is longer.
9 - 12	Acute shock appears in 1 min. Death occurs if the stay is longer.

There is a high correlation between the occurrence of anoxia symptoms and the rate of elevation gain. For example, 105 of the individuals who gain 4800m in altitude in a rather short period of time show major symptoms of anoxia, but only 59 in the case of slow elevation gain. A close relationship also exists between the duration of stay at high altitude and the occurrence of symptoms. The occurrence of symptoms prevails, and symptoms are aggravated as the duration prolongs. However, this trend will level off and stabilize after a few hours, and symptoms start to improve. This is due to the build up of adaptation ability to anoxia.

The major symptoms of anoxia are simply reflections of physiological reaction to its occurrence. The effect of anoxia on physiological functions is discussed in the following text.

B. O<sub>2</sub> partial pressure in alveolus and degree of  
O<sub>2</sub> saturation of blood during anoxia

Anoxia occurs as a result of the drop of O<sub>2</sub> partial pressure in pulmonary alveolus and blood. Therefore, this topic has to be extensively discussed.

(1) The trachea, bronchus, and bronchiole do not have a function of gas exchange, namely, both the inhaled and exhaled gas will partially remain in these areas. Therefore, these areas are called a "physiological residual zone". The size of the "residual zone" varies according to the respiratory function, but, generally speaking, the tidal air includes 150 ml. of residual volume for adults at rest. This observation implies that the O<sub>2</sub> partial pressure of inhaled air is higher than that of the pulmonary alveolus, and the CO<sub>2</sub> concentration is higher in alveolus than that in the inhaled air. Even if there is no air exchange in the alveolus, this difference of partial pressure still exists.

(2) The water content of pulmonary alveoli does not vary with that of the atmosphere because the pulmonary alveoli are always saturated with water at the normal body temperature (37°C). The H<sub>2</sub>O partial pressure stays constantly at 47 mm Hg. Based on this theory, the O<sub>2</sub> partial pressure in the bronchi can be calculated as follows:

$$P_{T O_2} = (P_B - 47) \times F_{I O_2} \quad (1)$$

$P_{T O_2}$  ; the partial pressure of O<sub>2</sub> in bronchus

$P_B$  : the surrounding atmospheric pressure

47 mm Hg: saturated partial pressure of water

$P_{IO_2}$  : the partial pressure of  $O_2$  in dry air

From this equation, it can be postulated that the  $O_2$  partial pressure in the bronchi drops more than expected as the atmospheric pressure drops. For example, the atmospheric pressure at an elevation of 9000m is 147 mm Hg, 19% of that at sea level, but the  $O_2$  partial pressure in the bronchi is 21 mm Hg, only 1/7 of that at sea level. This difference becomes more significant as the altitude increases.

According to the residual volume theory, it is impossible for the  $O_2$  partial pressure in the pulmonary alveoli to be the same as that of the bronchi. This difference will become more obvious as the oxygen is continuously absorbed into the pulmonary alveoli and  $CO_2$  is continuously expelled out. The partial pressure of  $O_2$  can be calculated from the following equation:

$$P_{AO_2} = F_{IO_2}(P_a - 47) - P_{ACO_2} \left( F_{IO_2} + \frac{1 - F_{IO_2}}{R} \right) \quad (2)$$

$P_{AO_2}$  : the partial pressure of  $O_2$  in pulmonary alveolus

$R$  : respiratory quotient

$P_{ACO_2}$  : the partial pressure of  $CO_2$  in pulmonary alveolus

$P_{IO_2}$  : the partial pressure of  $O_2$  in dry air

$P_B$  : the surrounding atmospheric pressure

No matter whether it is an air mixture or single element air, the gas always diffuses from higher concentration to lower concentration. Since tissues continued to consume  $O_2$

and produce  $\text{CO}_2$ , the  $\text{O}_2$  partial pressure in venous blood is always lower and the  $\text{CO}_2$  partial pressure is always higher than that in arterial blood. This can be observed both in the blood of pulmonary capillaries and pulmonary arteries. Oxygen leaves the alveolus and diffuses into the blood to make it oxygenated. Carbon dioxide leaves the blood and is expelled from the lungs. The drop of  $\text{O}_2$  partial pressure in inhaled air will cause a corresponding drop of  $\text{O}_2$  partial pressure in bronchi, pulmonary alveoli and arterial blood. It then leads to a decrease in the degree of  $\text{O}_2$  saturation and, indirectly, the drop of  $\text{CO}_2$  content in venous blood. As a result, the exhalation of  $\text{CO}_2$  will decrease, and the respiratory quotient will increase (the decrease in  $\text{O}_2$  intake is greater than that in the  $\text{CO}_2$  outgo). Table 3-2 shows the relationship between these factors.

TABLE 3-2 The  $O_2$  partial pressure, in bronchus and pulmonary alveolus,  $CO_2$  partial pressure in pulmonary alveolus,  $O_2$  saturation degree in arterial blood, and respiratory quotient at various altitudes

Elevation (1000 m)	Atmospheric pressure (mm Hg)	$O_2$ partial pressure in inhaled dry (mm Hg)	$O_2$ partial pressure in bronchi (mm Hg)	$O_2$ partial pressure in pulmonary alveoli (mm Hg)
0	760	159	149 ~ 150	101 ~ 107
1	674	141	131	90 ~ 92
2	596	125	115	70 ~ 75
3	526	110	100	61 ~ 69
4	462	97	87	50 ~ 56
5	405	85	75	43
6	354	74	64	40
7	308	65	55	34
8	267	56	46	26
9	230	48	38	21
10	198	41	31	17
11	169	35	25	13
12	145	30	20	-
15	87	18	0	0
Total trend	↓	↓	↓	↓

TABLE 3-2 (Continued)

Elevation (100 m)	CO <sub>2</sub> partial pressure in pulmonary alveoli (mm Hg)	O <sub>2</sub> saturation degree in art- erial blood (%)	Respiratory quotient
0	39 ~ 41	95 ~ 99	0.85
1	39 ~ 40	94	0.85
2	37	92	0.86 ~ 0.87
3	36	85 ~ 90	0.90
4	35	85	0.92
5	32	74	0.98
6	30	67 ~ 70	1.00
7	25	60	1.30
8	-	30	-
9	-	21	-
10	-	10	-
11	-	5 ~ 10	-
12	-	4	-
15	-	0 ↓	-

Note: "↓" indicates decrease, "↑" indicates increase

The degree of O<sub>2</sub> saturation in arterial blood (shown in Table 303), which is directly related to tissue anoxia, indicates how the blood supplies the tissues with oxygen. Table 3-2 further indicates the relationship between anoxia symptoms and the degree of O<sub>2</sub> saturation in arterial blood. It is shown in the Table that no significant symptoms will appear if the O<sub>2</sub> saturation degree in arterial blood is above 90% (which is approximately at an altitude under 2500m). The passenger airplane usually maintains the atmospheric pressure



in the cabin to this level. Considering older people and passengers with heart or respiratory problems, the air pressure is usually maintained above 630 mm Hg in the cabin of passenger airplanes. If compressed oxygen is used to increase the  $O_2$  concentration in the air, the total atmospheric pressure can be correspondingly lowered.

TABLE 3-3 The correlation between anoxia symptoms, altitude, and  $O_2$  saturation degree

Stage	Atmospheric altitude (100 m)		degree of $O_2$ saturation in arterial blood (%)	Major symptoms
	inhaled air	inhaled pure $O_2$		
no symptom	0 ~ 3	10.2~11.7	95 ~ 90	No significant symptoms except regressed night vision and change in electroencephalogram
Compensatory	3 ~ 4.5	11.7~12.6	90 ~ 80	No significant symptom shown due to the compensatory effect of body functions
impaired	4.5 ~ 6	12.6~13.2	80 ~ 70	Serious symptoms
serious	6 ~ 7	13.4~13.5	70 ~ 60	Loss of consciousness, risk of mortality.

### C. The gas exchange volume during anoxia and effect of exercise

There is no doubt about the fact that anoxia will enhance the air exchange volume of respiration. According to our observations, the following conclusions can be reached:

At altitudes above 3000m, the air exchange volume of lungs is enhanced approximately 5 - 10%; 20-25% increase for altitudes above 5000m; 50% increase above 6000m altitude; 100% increase above 7000-8000m. Violent exercise under an environment of thin air will enhance even more the air exchange volume of the lungs.

The enhancement of air exchange by anoxia is purely a compensatory reflex which mainly functions to compensate for insufficient  $O_2$  intake. Its mechanism is: The drop of oxygen concentration in the blood stimulates the chemical sensors in sinus jugularis and arcus aortae. This nerve impulse travels to the respiratory center of the medulla and respiration regulatory center of the midbrain to cause deeper breaths. As a result, the  $O_2$  partial pressure in pulmonary alveoli will be increased, and the symptoms of tissue anoxia will then be relieved. The increase of tidal air volume under anoxia is shown in Figure 3-5.

The vital capacity decreases as the elevation increases. At altitudes above 4000-5000m, the vital capacity of an average person will decrease 10-15%. Therefore, individuals have a certain difficulty in breathing at an altitude above 3000m. As for elevations above 5700m, even a small effort will cause panting. As the elevation increases, the time between breaths is shortened and panting is more serious.

Under anoxia, the so called "periodic respiratory symptoms" will appear. The depth of breath will change periodically from shallow to deep and then deep to shallow, or periodically a sudden deep breath changes gradually to shallow breaths, or a periodic alternate occurrence of deep breath and recess. Figure 3-6 shows a model case of this respiratory symptom.

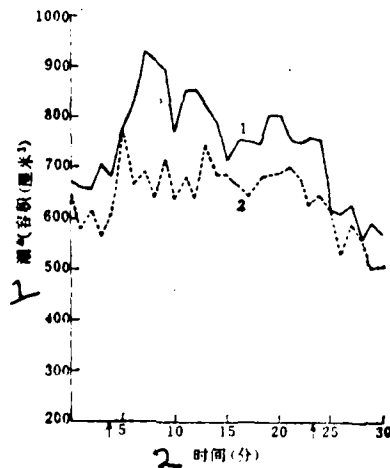


Figure 3-5. The effect of anoxia on tidal volume (The period between the two arrows in the x-axis is called "stage of anoxia"). Two curves indicate the results from the experiments.

Key: 1. tidal volume (mm), 2. Time (min)

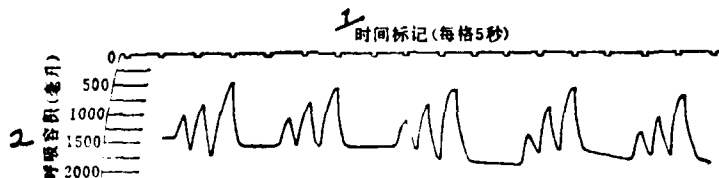


Figure 3.6. Periodic respiration.

Key: 1. time (5 second interval), 2. vital capacity (ml).

The occurrence of periodic respiration is a result of impairment of Hayward's reflex. Under normal circumstances, breathing is rhythmic. The mechanism of this rhythmic breathing is that the inhalation will expand the alveola wall to its limit and then the resilience reflex of the thoracic wall

forces exhalation to occur. Another possible mechanism is that the expansion of the thoracic wall stimulates the elongation sensors in it, and further inhibits the function of the inhalation center, which will, on the other hand, stimulate the exhalation center and induce active exhalation. When exhalation is very deep, it will stimulate another elongation sensor in the lung. This nerve impulse will travel along the vagus nerve to the medulla and induce inhalation. The normal rhythmic breathing is mainly a result of this Hayward's reflex. When anoxia occurs, the regulatory mechanism between the respiratory center in medulla and the elongation sensor of the lung is disturbed. Therefore, the normal rhythm and depth of breathing are destroyed, which results in periodic respiration.

#### D. The effect of anoxia on the cardiac circulatory system

There is a multiple effect of low-air-pressure anoxia on the cardiac circulatory system, which includes the heart beat, cardiac output, electrocardiogram, coronary circulation, capillary circulation, blood composition,  $O_2$  transportation, etc. Several items are discussed as follows:

##### 1. The change of heart rate and cardiac output

Under the circumstance of low-pressure anoxia (about 4000m elevation), the change of heart rate is not significant. However, as the elevation increases, the heart beat speeds up, as shown in Figure 3-7.

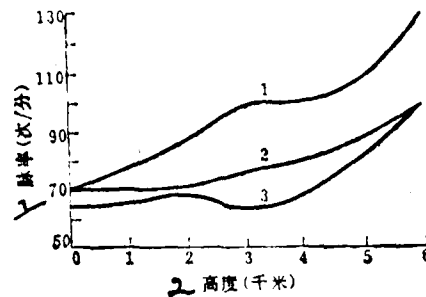


Figure 3-7. Increase in pulse rate as elevation increases.  
 1.2.3: results from 3 experiments.  
 Key: 1. pulse rate (times/min), 2. elevation (1000m)

One important well-known fact is that exercise will significantly increase the pulse rate. As for the effect of exercise on cardiac output per heart beat or per minute, it is still a controversial issue. Some groups observe a negative effect and some observe a positive effect. This contradiction may be caused by different experimental conditions (e.g., difference in altitude and duration). Generally speaking, exercise will increase the cardiac output per minute, because the heart rate will speed up no matter whether the output volume per beat will increase or not. If the duration of stay at high altitude prolongs, even the heart rate is still faster than that at sea level, but the output volume per minute will decrease mainly due to the smaller output volume per beat. Therefore, it can be concluded that the output volume per beat may increase or does not change at the early stage of mild anoxia, but it will decrease as the duration of anoxia is prolonged. The speed-up of heart rate and minor change of output volume per beat at the early stage may be due to the effects of excited sympathetic nerve and secretions from adrenal medulla. Acute anoxia will increase the concentration of meta-

bolism products of epinephrine or adrenalin-like substance in urine and blood plasma, and further increase the rate of heart beat and strength of contraction.

It has to be pointed out that the heart beat rate will only rise to a certain limit, beyond which even exercise cannot increase, and may even decrease the heart rate. Therefore, this mechanism explains why the speed and extent of exercise are limited during anoxia, and sometimes it may even be forced to stop.

## 2. Blood pressure of whole body and coronary circulation.

The effect of low-pressure anoxia on blood pressure of the whole body is not definite. There is a great variation among individuals and different elevations. Generally speaking, the blood pressure rises at elevations of 4000-5000m and drops at elevations above 6000m. For plateau (elevation above 4000m) residents, the arterial pressure is lower than that of plains residents. Under mild anoxia, the peripheral blood vessels will constrict, but the blood flow in the coronary artery has an increasing trend. Some animal studies show that the blood flow in the coronary artery increases 53% at an altitude of 3000-4000m, and 65% at 4500m elevation. From this result, it is indicated that the coronary branch circulation enhanced by chronic anoxia is a topic which deserves more extensive study.

## 3. Change in pulmonary circulation

It is concluded from all our research investigations that the pulmonary artery pressure of plateau residents is higher than that of plains residents. The pulmonary artery pressure will increase, especially more drastically during violent exercise, when an average individual suffers from intermediate

anoxia. This increase of pressure is caused by the constriction of pulmonary arterioles. After a long period of chronic anoxia, pulmonary arteriole walls will show morphological change (thickening of the walls), which is also the other factor to cause the pulmonary artery pressure increase. The elevated pulmonary artery pressure is an important factor for causing plateau pulmonary emphysema, which will be more extensively discussed in Chapter 6. Among local plateau residents, 20% suffer hypertrophy of the right ventricle. The same symptoms are found in the plain adults suffering pulmonary emphysema, which might be a response of the right ventricle to the prolonged effect of high altitude on pulmonary artery pressure.

The effect of altitude on other circulations remains unknown.

#### 4. Blood composition

The most significant changes are the increase of red blood cells and hemoglobin. At 4000m elevation over 1-2 weeks, red blood cells increase as the duration prolongs until they reach a maximum value of 7-8 million per cu. mm (normal value: 5 million per cu. mm). The increase of red blood cells and hemoglobin results from the hemocytoblast proliferation in red blood marrow stimulated by anoxia. This is a compensatory reaction of organisms to the insufficiency of  $O_2$  supply from blood. The increase in number of red cells increases the blood ratio volume and further the blood viscosity and peripheral resistance, which may be a supplementary factor for causing elevated blood pressure which results from intermediate anoxia.

#### 5. Electrocardiogram (ECG)

The effect of anoxia on the electrocardiograms (ECG) can be summarized as follows: No significant change can be observed

at elevations under 4000m. The effect of intermediate anoxia on ECG appears to be the drop of R wave and T wave, and fast heart beat. In the case of serious anoxia, changes include: ECG shows flat or reverse T wave and faster heart rate; P-T period drops below normal range; QRS compound wave drops; interval between P and Q is shortened; very slow heart rate appears after the occurrence of serious symptoms of heart problem; the sinoatrial node moves forward into the atrioventricular node. The reversion of T wave is an objective indication of malfunction of the heart. All the symptoms can be improved if oxygen is supplemented.

Most of the preceding symptoms occur in the circulatory system during acute intermediate anoxia. When anoxia reaches the critical stage (patient is almost in shock), usually at the altitude above 6000-7000m, symptoms such as significant drop of systemic circulation pressure and pulse rate, weak heart beat, weak pulse, and abnormal ECG, will occur.

It has to be emphasized that the endurance to anoxia varies greatly among individuals. Although some individuals seem to be strong, their endurance to high altitudes is worse than for those who seem to be weaker. There is no evidence to verify whether endurance is associated with certain kinds of nervous-type people. However, whether the individual is active seems to be an important factor in deciding his endurance to anoxia.

#### E. Change in metabolism under anoxia

Metabolism included processes from the ingestion, absorption, oxidation, and utilization of food to the excretion of the metabolic products. The anaerobic metabolism of carbohydrates, lipids, proteins and salt is discussed as follows:



1. Carbohydrate metabolism:

Carbohydrate catabolism can take place under either aerobic or anaerobic conditions. The catabolism products of proteins and lipids will join the aerobic metabolism of carbohydrates. The energy produced in the aerobic cycle is 19 times that in the anaerobic cycle. Under the normal circumstance, the energy for daily activities mainly comes from aerobic metabolism. Aerobic metabolism requires the catalytic involvement of enzymes. Therefore, the change of enzyme activity under anaerobic conditions deserves some attention because:

- a. The activities of some aerobic enzymes, such as cytochrome oxidase, cytochrome C, transaminase, increase under anaerobic conditions. The increased enzyme activity indicates the improved efficiency of energy production, which is helpful in improving the anaerobic situation. Under the same condition, the activities of some anaerobic enzymes (such as pyruvic kinase) decrease, and some (glucose-6-phosphate dehydrogenase and lactic dehydrogenase) increase.
- b. Glycogen, especially in heart muscle, is consumed very fast, but the situation can soon be reversed by the supplement of oxygen.
- c. The concentration of high-energy phosphate (such as glyceraldehyde-3-phosphate) in cardiac muscle, brain, and liver tissue decreases under anaerobic conditions. However, it is indicated in other reports that the concentration of high-energy phosphate increases during the early stage of anaerobic conditions, and then drops below the normal value later. All the results are obtained from small laboratory animals, which may not be able to be applied to human beings.

2. Lipid metabolism:

Low-pressure anoxia will decrease the total lipid content in blood, but gradually increases the concentration of cholesterol and phospholipid in blood. Under the condition of low  $O_2$  partial pressure, the lipid metabolism will be enhanced. If the chronic anoxia is continued, the body fat will be lost and so will the body weight.

C. Metabolism of protein:

According to recent reports, it is indicated that chronic  $O_2$  shortage will enhance the synthesis of protein and nucleic acid in brain tissue and cardiac muscle, which is helpful in  $O_2$  compensation and adaptation to anoxia. On the contrary, the synthesis of the former compounds is decreased in liver, spleen, duodenum.

D. Metabolism of water and salt:

As for the physiological responses to anoxia, the symptom of respiratory alkali toxication (tremendous loss of  $CO_2$  due to deep breath) has long been reported and verified. Under the circumstance of insufficient  $O_2$  supply, the  $CO_2$  content in blood appears to decrease, and so does the  $CHCO_3$  concentration in plasma. However, this can be compensated by increasing the supply of Cl, positively-charged protein molecules and inorganic phosphate. The diffusion of water into cells results in the decrease of extra-cellular fluid and corresponding decrease of electrolytes, such as  $Na^+$ ,  $Cl^-$ , and  $HCO_3^-$ . It has been reported that sudden exposure to an  $O_2$ -insufficient environment caused by low atmospheric pressure will result in, first, increased excretion, then retention of sodium and potassium, and elevation of potassium level in blood plasma.

Under the circumstance of serious  $O_2$  shortage, the potassium in nerve cells will gradually disappear and sodium will be retained; therefore, the nerve cell will lose its ability of polarization, which will inhibit the transfer of nerve impulses. Cold and  $O_2$  shortage will both inhibit the transfer of sodium ions, which has been indicated as a causing factor of plateau pulmonary emphysema.

#### F. The Effect of Anoxia on the Nervous System

1. The response of the central nervous system and hypothalamus adrenals system to anoxia:

The response of nervous-endocrine system to anoxia, especially the interaction between the nervous system and the anterior lobe of the hypothalamus and adrenals, is discussed in this section. At the early stage of anoxia, sympathetic nerves and adrenal medulla are stimulated, which results in a faster heart beat, deep breaths, elevated blood pressure and enhanced energy metabolism. Then, the anterior lobe of the hypothalamus activated by nerve center will excrete corticotropin-releasing hormone (CRH), which will stimulate the adrenal cortex to release corticosterone and then induce the compensatory and adaptation function in the body. However, over-active adrenal cortex will result in a harmful effect, namely, insufficient adaptation syndrome. The nervous and hypothalamus-adrenals systems can regulate each other's functions. During anoxia, the trigger of adaptation mechanism is located in the central nervous system, the function of the anterior lobe of the hypothalamus, and the adrenal cortex will respond accordingly. The secreted hormones exert feedback reactions on the corresponding part in the central nerve system and endocrine secretion itself.

## 2. Electroencephalogram (EEG)

During anoxia, the typical EEG changes include the occurrence of increased amplitude, and low-frequency waves (frequency lower than 7 cycles/sec). If individuals stay at the elevation above 5000m for a prolonged period of time, low-frequency (6-8 cycles/sec), high amplitude waves can be seen. As the anoxia is getting more serious, frequency continues to decrease gradually. The occurrence of low-frequency waves of 2-4 cycles/sec is an indicator of losing consciousness. EEG will disappear completely during unconsciousness, but can be recovered gradually with adequate supply of  $O_2$ . The occurrence of low-frequency waves and loss of pattern indicate that the normal function of brain cells is inhibited due to the inadaptability to oxygen shortage. Most well-adapted individuals show normal EEG with dominant  $\alpha$ -pattern when they are seated quietly with their eyes closed. If the basic pattern of EEG is about to disappear, it implies that the adaptation is not very successful.

## 3. Functional change:

$O_2$  shortage generally shows inhibitory effect on both conditioned and unconditioned reflexes, but occasionally demonstrates stimulated and anti-inhibitory effects on certain reflexes. For example, the inhalation of air containing 6%  $O_2$  for 18 min. can speed up the spinal reflex of lower limbs. The carotid sinus reflex is excited when the  $O_2$  partial pressure in venous blood drops below 19 mm Hg.

It should be indicated that the histo-pathological examinations show the following results when an individual suffers anoxia for a long period of time: capillary hemorrhage; edema; proliferation of lymphocytes and monocytes; different degrees of functional changes of nerve cells at cerebral and cerebellum

cortexes, thalamus, white nucleus, red nucleus, etc; complete loss of function of the central nervous system due to more serious anoxia.

The reasons why the central nervous system is so sensitive to  $O_2$  shortage are as follows: (1) The storage of nutrients in the nervous system is very limited, and the brain metabolism mainly depends on the aerobic oxidation of carbohydrates

(2) The storage amount of high-energy organic phosphate in the brain is less than half of that in muscle. Cessation of immediate supply of nutrients will cause the storage to be depleted in a short period of time, even during mild exercise. The storage can be restored only under the aerobic environment. Therefore, the brain activities need continuous supply of  $O_2$  and even short interruption will cause the malfunction of brain tissue.

#### IV. Working ability under $O_2$ shortage

##### (A). Physical strength

Above 3000m elevation, the average individual will show weaker physical strength. When the atmospheric pressure drops below 535mmHg, the walking ability decreases an average of 5%. At an atmospheric pressure of 464mmHg, intensive exercise will decrease the maximum  $O_2$  inhalation by 25% compared to that at sea level. The physical strength during  $O_2$  shortage is highly correlated to the  $O_2$  volume inhaled. For example, the maximum walking ability at sea level is 1500-1600Kg·m/min, and  $O_2$  inhaled per minute is 3.71 liter. At the elevation of 4600m, the maximum physical strength is 800Kg·m/min, and the  $O_2$  inhaled per minute is only 1.5 liter.

The decrease of physical strength also appears as a significant increase in respiration rate, heart rate, blood pressure and sweating, which also occurs during intensive athletic exercises.

(B). Effect on sensation

The effect of anoxia on sensation is more significant, especially vision impairment. From the elevation of 2000m, visual function starts to change gradually, especially night vision. Brightness threshold value and the duration of after-image (usually lengthened in the case of anoxia) will change aggravatingly as the elevation increases. The retrogression of night vision at elevations above 2000m becomes very significant. As for brightness threshold and the duration of after-image, the aggravating change will not become significant until the elevation reaches 3000-4000m. As a whole, the degeneration of visual functions including poor dark adaptation, eye muscle fatigue, color blindness, vision insensitivity, smaller vision field and study inefficiency, starts to show from 2000-3000m elevation and becomes significant at 4000-5000m elevation.

Eye movement, internal pressure and pupil contraction are insensitive to  $O_2$  shortage. No functional change will appear until the elevation reaches 4000-5000m, and not until 5000-6000m elevation will the aggravating effect becomes significant.

The effect of anoxia on the taste sense appears to be the change of favorite flavor, e.g. the sudden interest in sour food, corned beef and loss of interest in sweet drinks. At elevations above 5000m, some people cannot differentiate the taste of green onion from that of black pepper. These changes indicate the change in functions of all the sensory system, including the sensors and corresponding central nervous system.

The effect of anoxia on hearing and balance will not show below 4000m elevation. The cutaneous sensations appear to be over-sensitive at 2.4-4.5Km elevation, and start to be dull at elevations above 4800m.

(C). The effect on maneuverability

Trembling of hands, as the first symptom, appears at 2000m elevation, and becomes prevailing above 3000m elevation. For example, a writing test shows that handwriting starts to change above 2400m elevation, and becomes significantly worse above an elevation of 3300m, and becomes unreadable for most of the individuals who are not adapted to high altitudes above 5000m.

Most of the hand operations, such as drafting, perforation, and decoding, and efficiency of visual selection, start to degenerate at altitudes of 3000-4000m, and become significantly worse at 5000m elevation.

Muscle strength, tracing, balance, instant memory, sense of timing and alertness start to degenerate above 4000-5000m, and become significantly worse as the elevation increases.

It can be calculated that, for most of the poorly-adapted individuals, the termination of  $O_2$  supply above 6000m will cause the degeneration of flying and working abilities to an unsafe degree.

V. Endurance to Anoxia

(A). Effective consciousness time and subjective endurance limit

Many different criteria can be applied to determine the endurance to anoxia. The endurance threshold value depends on the method being used. The most commonly used criterion of anoxia endurance is called the effective consciousness time. The effective consciousness time refers to the period between the occurrence of anoxia to the complete loss of effective working ability. Many different definitions are made about the complete loss of effective working ability. The most commonly used criterion is writing ability. In addition to that, the loss of maneuverability and response ability are also used as criteria to determine the loss of effective working ability. The complete loss of effective consciousness means the loss of flying ability which will threaten the safety of the pilot. In other words, the effective consciousness time refers to the period from the occurrence of anoxia to the impairment of flying ability. This is still a problem in aeronautics which deserves more research. Figure 3-8 summarizes the results from different critical criteria and perspectives. Curve no. 3 in this figure indicates that even with the inhalation of uncompressed pure  $O_2$ , the loss of effective consciousness still occurs above 4700ft due to the  $O_2$  shortage resulted from low-atmospheric-pressure.

If the anoxia is caused by gradual decrease of atmospheric pressure, not by the sudden interruption of  $O_2$  supply, the rate of pressure loss will make a great difference to the effective consciousness time, as shown in Figure 3-9.



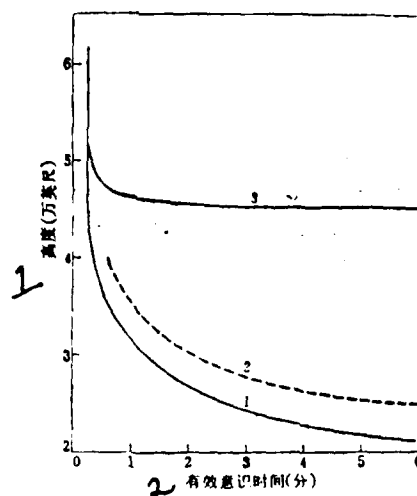


Figure 3-8. The effective consciousness time during anoxia.  
 1. Inhalation of surrounding air.  
 2. Sudden interruption of  $O_2$  supply at certain altitudes.  
 3. Inhalation of pure  $O_2$  as the surrounding atmospheric pressure drops.  
 Key: 1. elevation (10,000ft), 2. Effective consciousness time (min.)

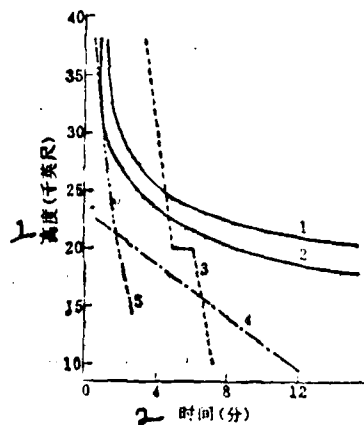


Figure 3-9. The comparison of effective consciousness time during anoxia and the safety limit of flying ability.  
 Curve 1: Effective consciousness time. Curve 2: Safety limit of flying ability. Curve 3: Plane descends from 70,000ft elevation.  
 Key: 1. elevation (10000ft), 2. time (min.)

The above 3 curves indicate that the inhalation of only surrounding air, not pure  $O_2$ , will cause a pilot to lose effective consciousness before the plane even descends to the safe elevation. Curves 4 and 5 show the descending of planes from 1150 ft. and 40000 ft elevation. This kind of flight is considered to be safe.

When major symptoms of anoxia reach an intolerable limit, it is called the major tolerance limit. According to the survey materials, most individuals reach this limit within one hour at the elevation of 6000m, and have to use oxygen supply. It has been suggested that the major tolerance limit is the indication of the starting point of  $O_2$  supplementation. However, we think this criterion is too risky and not practical because when pilot reaches this tolerance limit, he might have already exceeded the safety limit of flying ability. For safety reasons, the pilot should be allowed to use  $O_2$  in the first hour at elevation of 3000-4000m. As for the passengers, this criterion does not have to be followed strictly. Nevertheless, the  $O_2$  partial pressure and atmospheric pressure in the cabins of modern passenger jet planes and military transport are constantly kept at those for physiological need. Unless an accident happens, the problem of anoxia should not happen. Therefore, the major tolerance limit can be used only as a reference for engineering design and the flight crew. It does not have too much practical value any more.

### B. Unconsciousness and collapse time

Some reports have suggested use of the occurrence of serious physiological symptoms as indicators of a safety margin, known as the unconsciousness or collapse time. But we think it is too risky and impractical to use this criterion as a safety margin. Nevertheless, in order to figure out the

possible longest time for self-survival measures during airplane and spaceship accidents, the designer can use the collapse time as a reference in their safety design. Besides, these data have practical meaning to the pilot in estimating the escape time. The unconsciousness time and collapse time are discussed in more detail as follows:

1. Unconsciousness time

It is commonly accepted in aeronautics that  $O_2$  supplementation is required at a certain elevation. It is necessary to find out the time interval between interruption of the  $O_2$  supply and loss of consciousness when abrupt interruption of the  $O_2$  supply occurs. Therefore, emergency measures can be adopted before the loss of consciousness. From this point of view, the study of the unconsciousness time seems to be more practical and meaningful. Figure 3-10 indicates the unconsciousness time at different altitudes as the  $O_2$  supply is interrupted. The effective consciousness time is also listed in the figure for comparison. Above 40,000ft, the 2 curves overlap, which indicates that the inhalation of the surrounding atmosphere above this elevation will result in unconsciousness.

In the passenger flight, all the necessary procedures required to recover the  $O_2$  supply should be adopted immediately before the unconsciousness starts to occur. For most of the individuals, the time interval between interruption of the  $O_2$  supply and loss of unconsciousness is about 1/3-1/15 of that before death occurs. From the physiological point of view, as the hemoglobin saturation degree drops below 56% and  $O_2$  partial pressure in pulmonary alveoli drops below 20 mmHg, the symptom of unconsciousness will appear within 14 seconds.

When an individual loses his consciousness due to  $O_2$  shortage, emergency treatment, such as application of a respirator, should be adopted within 3-4 seconds. Otherwise, the victim will soon suffer shock. However, some exceptions do exist. For example, if the individual is just on the critical margin of unconsciousness (hemoglobin saturation degree about 65% and alveolus  $O_2$  pressure at 20 mmHg), consciousness may be recovered after being unconscious for 17 seconds due to the functioning compensatory mechanism in the individuals. Under this circumstance,  $O_2$  still needs to be supplied immediately after the patient regains consciousness, otherwise other symptoms of anoxia may still occur later on.

Unconsciousness time is generally longer than the effective consciousness time. Above 9000m elevation, the unconsciousness time is about 25-30% longer than the effective consciousness time. The higher the altitude, the less the difference is. At altitudes above 10,500m, both values are almost the same. Their relationship is shown in Table 3-4.

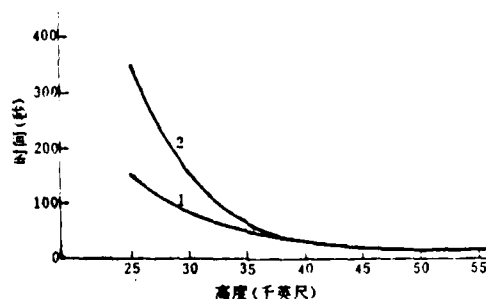


图3-10 缺氧的有效意识时间和失意识时间的比较 (呼吸周围空气)  
1—有效意识时间; 2—失意识时间。

Figure 3-10. Unconscious time versus altitude  
1 - conscious time; 2 - effective conscious time;  
3 - altitude, (ft.); 4 - time, (secs.);

TABLE 3-4. The effective time and unconsciousness time during anoxia

Elevation (1000m)	Effective consciousness <sup>(1)</sup> time (sec)	Unconsciousness time (sec)
7.5	120 ~ 180	420 ~ 240
9.0	70 ~ 90	120 ~ 180
10.5	45 ~ 60	60
12	30 or below	-
13.8	15	15
15	15	15

### B. Shock (or collapse)

The occurrence of shock is a dangerous symptom of anoxia. An average person will suffer shock as the  $O_2$  concentration in the atmosphere drops to 7.3%.

For most people, staying at 7000-8000m elevation for more than ten minutes will result in death. However, about 1/3 of the human beings with high endurance to high altitude will not be threatened by death until 9000m elevation. On the contrary, 1/5 of the population with poor endurance will run into the danger of mortality, even at the altitude of 6000-7000m. At 7000-8000m elevation, death usually occurs 11-60 min. after the interruption of the  $O_2$  supply, but may be sooner (in 3 min) or later (more than 1 hr) in some special cases.

All the preceding data are only referred to those who are not mountain inhabitants. The endurance to  $O_2$  shortage for mountain residents will put them into another category to dis-

<sup>1</sup> Degenerated handwriting is used as the criterion for effective consciousness time.

cuss.

C. The factors which affect the endurance to  $O_2$  shortage:

The endurance to  $O_2$  shortage depends on many different factors, such as:

1. The slower the  $O_2$  shortage occurs (e.g. slower elevation gain), the better the endurance is.
2. The endurance is better for healthy individuals.
3. The better the adaptation to altitude, the better the endurance is.
4. Endurance is better for non-nervous type individuals.
5. Endurance is better for strong-willed, active individuals.
6. Endurance is worse for smokers, alcoholics, and individuals with circulatory problems.

Other physical conditions, such as overweightness, fever, fatigue, exhaustion, will decrease the ability of endurance, but, electrolic dissociation radiation, on the other hand, will improve the endurance.

VI. Adaptation to Anoxia and Mountain Sickness

The training of adaptation to anoxia, namely, improvement of endurance to  $O_2$  shortage, is a good way to improve the working ability and relieve the symptoms during  $O_2$  shortage. It has important practical meaning in both aeronautics and space travel. The study of adaptation to anoxia resulting from low atmospheric pressure is usually performed in mountain or plateau areas. Therefore, it is basically the same as the training of altitude adaptation. Mountain sickness actually is just an inadaptability to hypobarometric anoxia. The hypobarometric anoxia, (or low-atmospheric-pressure anoxia),

instead of mountain sickness, will generally be used in this chapter.

A. General observations of adaptation to anoxia

A certain degree of adaptation can be built up if an individual stays in anoxia conditions for a period of time. The uncomfortable symptoms appearing at the early stage of anoxia can be relieved significantly, which is called adaptation to anoxia. For example, the effective consciousness time will be significantly prolonged in the 5th week of continuously staying at 3000-4000m elevation. After this adaptation, all the tested individuals can stay conscious for 30 min. in the decompression chamber (simulating the altitude of 7500m), and their coordination effectiveness drops less than 10% compared with that under normal atmospheric pressure. In the early stage of mountain training, fatigue and decreased efficiency in daily routine are easily found, but not after the gaining of adaptation.

The development of adaptation can also be easily found among mountain climbers. For example, if an individual is not accustomed to high altitudes, his climbing activity will be slowed down by 12.3% from 1650 to 4100 m elevation due to lack of endurance to anoxia. On the contrary, the individuals with well-developed adaptation to altitude will not be affected by change of elevation. After camping 20 days at 4100m elevation, the endurance to anoxia will be improved by 20% for individuals in both categories.

Mountain inhabitants and people who travel a lot in mountain areas have higher endurance to anoxia, which is so called "natural adaptation". This kind of adaptation can be

shown by experiment: Both mountain and plains residents are placed in a decompression chamber which will simulate the elevation gain at a speed of 25m/sec. This experiment chamber also simulates two 5-min stops at elevations of 5000 and 6000m and one 30 min stop at 7000m elevation. The result shows that only 15% of the plains residents can stand the 7000m elevation for 30 min, but 90% of the mountain residents can stand the 7000m for more than 30 min.

The adaptation to altitude can be trained to improve more as the elevation increases. However, if the elevation gain is not significant, the further improvement in adaptation will not show significant results.

The adaptation to lower altitudes will increase the endurance to anoxia at higher altitudes. For example, an individual who resides at 3000m elevation for several months will have a longer effective consciousness time at an elevation of 8000m compared to those who did not develop into adaptation to 3000m elevation.

#### B. Duration to reach complete adaptation and extent of mountain adaptation

How long does it take to reach complete adaptation? It all depends on the approach you use to gain adaptation. If the appropriate approach is used, adaptation can be reached in a rather short period of time, which will be discussed in more detail in the following text. How long a plains resident takes to adapt to mountain living completely is shown in Table 3-5. It is indicated in the Table that the increase in altitude will prolong the duration to reach complete adaptation: e.g., the duration to reach complete adaptation will be



prolonged 2-3 weeks per 1000m elevation gain above 3000m elevation, and will be 11-12 weeks longer above 6000m elevation.

Although it takes several months to gain complete adaptation, the adaptation develops faster in the first 2 weeks of mountain climbing. The development of adaptation slows down after 2 weeks.

It should be pointed out that the so called complete adaptation, basically, has reached the maximum limit of adaptation. Although this point is not the end of adaptation, no significant improvement can be obtained beyond this point. A mountain climber with years of experience will never adapt to high altitude as well as the mountain aborigines. The adaptation may still be able to improve, but not significantly.

Can people be adapted to any elevation, even extremely high altitude? Is there a limit to mountain adaptation? It is observed that, at altitudes above 6000m, no matter how long the mammals stay, the symptoms of anoxia cannot be relieved completely. Autopsy results indicate the impairment and malfunction primarily in the circulatory and respiratory systems, liver, kidney, and spleen congestion and failure. Only the nerve cells are not significantly affected. From the above results, it is postulated that, maybe, 6000m is the highest altitude an animal will be able to adapt to. However, some groups also indicate that 7000m is the maximum altitude limit.

Experience tells us that above 5400m elevation, most of the people will show, more or less, some symptoms of anoxia no matter how long they have been staying at that altitude. Therefore, if any individual plans to reside above this elevation, it is necessary to adapt to this altitude and also

take some precautionary treatments. For some mountain climbers, 5000 ft does not seem to be the maximum adaptable altitude. Even people show various symptoms above 5400m elevation, which does not mean they cannot reside at this altitude, but only indicates that the work efficiency will decrease. It has been reported that individuals residing at 5790m elevation for 5 months show better adaptation, but still lose some weight. Whether this weight loss can be recovered by better nutrition or working schedule remains unknown.

Although adaptation to 5000-6000m elevation is believed to be rather difficult, it is possible to improve the adaptation by active mobility and appropriate treatments (such as diet, working schedule, training). Then the long-term residable altitude may be raised.

The principles of adaptation to altitude also apply to high and low temperature; therefore, we will not discuss other kinds of adaptation in details.

### 3. Mechanism of Anoxia Adaptation

Anoxia adaptation is just one of the physiological functions. The results of the study are summarized in Table 3-6. The data listed in Table 3-6 are discussed in the following categories:

#### 1. Respiration:

The adaptation will increase respiratory rate and depth, then expand the thoracic cavity. The pulmonary circulatory function and gas diffusion ability will also be improved. All

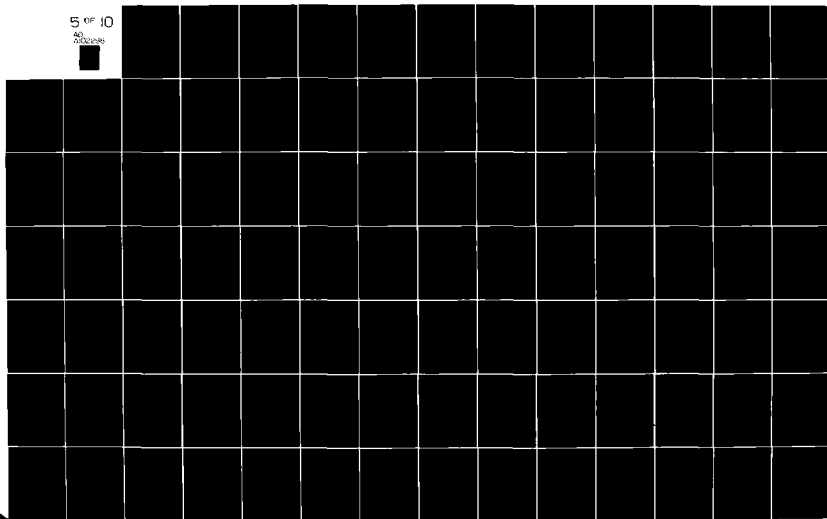
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these indicate that all the pulmonary functions can easily adjust to the body requirements and locally compensate for the decreased  $O_2$  partial pressure. Therefore, the  $O_2$  partial pressure in the pulmonary alveolus and artery,  $CO_2$  partial pressure in the pulmonary alveolus and artery are very close to those at sea level.

## 2. Circulation and metabolism

The major adaptation in the circulation appears to be the elevation of red blood cell and hemoglobin level, increased oxygenation, faster circulation, which will enhance the  $O_2$  transport in the blood. The adaptation in metabolism appears to be an improved buffering function in the blood and improved lactate and glucose metabolism, which will meet the metabolism requirements at the desired altitude. The enhanced pulmonary and brain circulation will insure the normal functions of the respiratory center, cerebrum, and other centers. However, the symptoms of anoxia occur at the coronary artery, which can cause cardiac and further cardiac failure under prolonged anoxia. If this happens, cardiac output and blood pressure will decrease, and eventually result in non-adaptation. It has been suggested that degeneration of cardiac functions during anoxia is a weak point in anoxia adaptation. Overcoming this weak point will certainly increase the adaptation ability.

## 3. Central nervous system

It has been pointed out in the preceding text that anoxia will affect the carbohydrate metabolism in cerebral cells, release of hypothalamus-adrenal corticosterone and activities controlled by the cerebrum. It is also shown in Table 3-6 that these symptoms are improved by the adaptation to anoxia.

As we discuss the mechanism of anoxia adaptation, it is necessary to emphasize once more the importance of an improvement in the function of the central nervous system. The improvement is based on the carbohydrate metabolism and nervous-endocrine system, and results in the recovery of mental and physical activities.

#### 4. Other Factors

Adaptation also occurs in the muscle and endocrine system. It occurs significantly in:

(1) The efficient consumption of  $O_2$  and enhanced storage (faster synthesis) of the glycogen in muscles, which have a significant effect on the improvement of physical activities and endurance during  $O_2$  shortage.

(2) The hypothalamus-adrenal cortex regulating mechanism which will be enhanced to reach a better balance between energy and material metabolism.

Anoxia adaptation not only improves the endurance to anoxia and the activity ability during  $O_2$  shortage, but also improves physical strength, weight, endurance under normal atmospheric pressure. It also has significant effect on the training for physical strength and endurance of flight crews and athletes.

TABLE 3-6 The physiological effect of anoxia and adaptation to anoxia

Physiological category	Individual items	Changes at the beginning of climbing (compared with sea level)	Changes after adaptation (compared with the beginning of the climb)
Respiration	pulmonary air (rest) exchange vol. (exercise)	+	+
	respiration rate	+	+
	depth of breath	+	+
	vital capacity	+	+ (recover to the value at sea level)
	tidal volume & max. respiratory vol.	+	+
	respiratory quotient	+	+
	ability to hold breath	+	+
	thoracic cavity	no change	+
	diffusion ability of gases at pulmonary alveoli	no change or +	+
	O <sub>2</sub> partial pressure at pulmonary alveoli	+	+
Respiration	O <sub>2</sub> partial pressure in artery	.	+
	O <sub>2</sub> saturation degree in arterial blood	+	+
	CO <sub>2</sub> partial pressure at pulmonary alveoli	+	+

TABLE 3-6 (Continued)

Physiological category	Individual Items	Changes at the beginning of climbing (compared with sea level)	Changes after adaptation (compared with the beginning of the climb)
	CO <sub>2</sub> partial pressure in arterial blood	+	+
Coronary circulation	heart beat and pulse rate (rest and exercise)	+	+
	cardiac output per hear beat	+	+
	cardiac output per minutes	+	+
	arterial & venous blood pressure	+	+
	O <sub>2</sub> partial pressure at coronary artery	+	+
	pulse pressure	+	+
	blood flow at brain	+	+
	no. of red blood cells	+	+
Blood composition	red cell formation enzyme	+	+
	red blood cell/white blood cell ratio	+	+

TABLE 3-6 (Continued)

Physiological category	Individual items	Changes at the beginning of climbing (compared with sea level)	Changes after adaptation (compared with the beginning of the climb)
	concentration of hemoglobin	+	+
	plasma and blood volume	+	+
	pulmonary blood flow	+	+
	plasma protein conc.	+	+
	water content in blood	+	+
	concentration of lactage	+	+
	concentration of glucose	+	+
	buffering mechanism in blood	no change	+
metabolism	basal metabolism	+	+
	regulation of body temp.	no change	no change
	body weight	+	+
endocrine	adrenalin		+
	noradrenaline		+
	thyroxine		+



TABLE 3-6 (Continued)

Physiological category	Individual items	Changes at the beginning of climbing (compared with sea level)	Changes after adaptation (compared with the beginning of the climb)
immunology	water retention indicator	+	+
	immune system	+	+
	slow wave of EEG	+	no change
exercise	physical strength	+	+
	efficiency	+	+
	O <sub>2</sub> efficiency and storage during exercise	no change	+
endurance	body endurance	+	+

+ increased activities

+ decreased activities

#### D. Approaches to develop adaptation to anoxia

How can the adaptation be developed without any suffering? The resolution is especially important to the transport of military supplies on plateaus. Unfortunately, this problem has not been completely solved yet. Following is a summary of study subjects in this area:

##### 1. Adaptation to higher altitudes

In order to develop an adaptation to certain altitudes, training should take place at 900-1500m higher than the desired altitude. In this way, adaptation develops faster and better. Table 3-7 shows the result of this training approach.

TABLE 3-7 The postulation of training altitude and duration

Altitude to be adapted to (m)	Training altitude and duration of training
3050	4100m, 2 weeks
4300	5800m, 2-3 weeks
5180	6700m, 3-4 weeks
5800	6700m, 5-6 weeks

##### 2. Intermittent vs. continuous elevation gain

Both approaches of intermittent and continuous elevation gain are compared as following. A continuous elevation gain is to climb to 4300m elevation without any prolonged rest on the way. Intermittent elevation gain is to stop at 1610m elevation for one week, then at 3475m elevation for another

week, before one reaches 4300m elevation. The results show no significant difference in the change of maximum respiratory volume during exercise, total exercise capacity, pulse rate, and cardiac output between these two groups. But the anoxia symptoms occur less frequently in the intermittent group. Therefore, it can be concluded that the adaptation can be reached faster in the continuous approach, but more comfortable in the intermittent approach.

### 3. The effect of exercise training during adaptation

In the preceding study, the subjects are divided into two groups: One group just sits and rests all day long (control group). The other group does exercises for half the day, and rests for the other half of the day (exercise group). The results show no significant difference in maximum respiratory volume (either during exercise or rest), pulse rate, and cardiac output between two groups. However, more individuals in the exercise group show increased total exercise capacity (exercise group, 6/8; control group, 3/8) and more individuals in the control group show decreased exercise capacity (exercise group, 2/8; control group, 5/8). Therefore, it can be concluded that the appropriate exercises during adaptation can increase exercise capability with a  $O_2$  shortage environment.

### 4. Natural adaptation vs. non-natural adaptation

Mountain inhabitants possess high endurance to anoxia due to developed adaptation to high altitudes. Can plain residents obtain the same degree of adaptation if they stay at this altitude for a considerable period of time? It is indicated in the early study that individuals who stay in the mountain for

a period of time can adapt to high altitude as well as mountain inhabitants in many ways. However, recent studies contradict these early reports. It is indicated in recent studies that no matter how long plain inhabitants stay in the mountain, some physiological functions, such as maximum pulmonary exchange volume, maximum  $O_2$  intake, pulse rate, pulmonary and venous  $CO_2$  concentration, can never reach the standard of mountain residents. Why? According to our study, we have to admit that how long has the mountain adaptation been developed is an important factor, as shown in Figure 3-11.

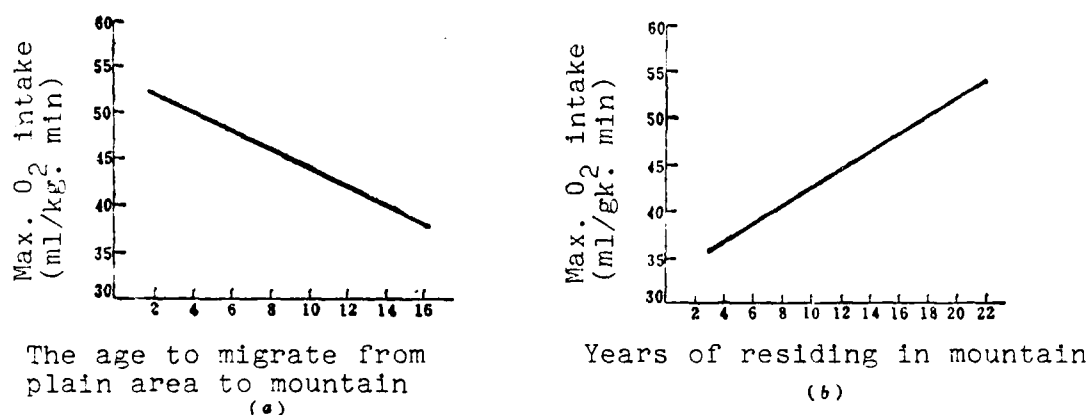


Figure 3-11. The relationship between  $O_2$  intake and plateau adaptation.

It is shown in Figure 3-11 that the earlier does the family move, the greater the maximum  $O_2$  intake is; the longer one lives in the mountain, the greater the maximum  $O_2$  intake is. This implies that, as far as the maximum  $O_2$  intake is concerned, the longer you stay in the mountain, the better the

adaptation can be. However, it cannot be ignored that the adaptation mechanism of mountain aborigines is not quite the same as that of plain residents. For example, under the same metabolic rate and activities, mountain aborigines who reside at 4880m elevation have less pulmonary gas exchange than that of plain residents who have been adapted to this altitude for 3 1/2 weeks, but the  $O_2$  inhaled volume is higher in the former. Therefore, it is suggested that the adaptation of individuals who are not well adapted yet depends mainly on the compensatory function of respiration and circulation. The mountain aborigines, on the other hand, depend mainly on the compensatory functions at the cellular and molecular level. Besides, it should be emphasized that adaptation is easier to develop among youngsters, which is also lasts longer. It has been reported that if mountain-born children immigrate to plains and stay there for a long period of time, their pulmonary gas exchange will not increase significantly (only  $0.4 \pm 1.9 \text{ e/m}^2 \cdot \text{min}$ ) even when their arterial  $O_2$  pressure drops from 150 mm Hg to 40 mmHg under  $O_2$  shortage conditions. But for children grown in the plains, the pulmonary gas exchange will increase significantly ( $9.7 \pm 7.0 \text{ e/m}^2 \cdot \text{min}$ ) under the same conditions. The only explanation for this is that the immigrants from mountain areas only reside at this high altitude for several years. They already develop a stable and long-lasting adaptation mechanism to anoxia, which cannot be found among plain residents.

#### E. Degeneration of adaptation

The plain residents who are already adapted to high altitudes will lose significantly their adaptation ability after they return to plain areas for 3-4 weeks. If they return to the high mountains at this time, the symptoms of

anoxia will reappear, and sometimes even worsen, which indicates that they already lose the developed adaptation ability while staying at plain area for a period of time. It is necessary to expose oneself regularly to an  $O_2$ -shortage environment in a decompressed cabin. This is a general practice in flight training.

Individuals who have adapted well to high altitudes, especially the mountain aborigines, will not easily or never lose their adaptation ability. It has been reported that after the mountain aborigines (residing at <sup>4540</sup>~~5450~~m elevation) immigrate to plain areas for 2 years, their heart rate slows down, cardiac output drops during rest, the pulmonary arterial pressure and the resistance in the pulmonary blood vessel decreases significantly, but no significant change occurs in the arterial blood pressure. When they exercise, the average pulmonary arterial pressure is still higher than that of the plain residents. However, their adaptation to anoxia can soon be recovered as they return to the mountains, which indicates that they still keep their adaptation ability when they stay on the plains.

#### F. Mountain sickness

Most people will adapt to, more or less, high altitudes after a period at 5000m. However, in some rare cases, adaptation can never be developed and anoxia symptoms will be even aggravated and result in mountain sickness as the duration of stay prolongs.

The occurrence of mountain sickness within one month is referred to as acute mountain sickness, which is difficult to differentiate from acute anoxia symptoms. The symptoms of

patients suffering the mountain sickness will not disappear or improve as the duration of stay prolongs; sometimes they will even be worsened. Mountain sickness occurring after the first month is called chronic mountain sickness. In this case, symptoms will appear on and off, and will aggravate if no appropriate measures are taken.

Not only is the disease mechanism of mountain sickness still a subject of controversy, but the classifications of it as well. It is accepted that the excessive amount of hemoglobin cannot be the major cause of mountain sickness, because these factors will only result in an increase of blood viscosity and elevated blood pressure. But, in a  $O_2$ -shortage environment, the construction pressure of arteries in general circulation will not increase significantly, and will not cause typical symptoms of mountain sickness.

It has been suggested in many reports that the primary cause of mountain sickness is pulmonary arterial hypertension resulting from the low  $O_2$  partial pressure in the pulmonary alveolus. This low  $O_2$  concentration will induce the pulmonary arterioles to constrict, and further hypertrophy of right ventricle, thickening of the pulmonary artery and arteriole walls, increased resistance, the decreased diffusion ability of pulmonary alveolus, and eventually pulmonary emphysema. These physiological and pathological changes cause a virulent cycle which will, in feedback, aggravate the symptoms of mountain sickness. The autopsy examination and tissue slides of deceased patients and animals all support the above hypothesis. According to the preceding observations, it can be concluded that pulmonary emphysema is the most common symptom of acute and chronic mountain sickness, which, therefore, is also referred to as a pulmonary emphysema type of sickness.

Another type of mountain sickness is characterized by the occurrence of insufficient cardiac blood supply. The incidence is rather rare, but the symptom is more severe. It usually occurs in the acute mountain sickness case. Mountain residents seldom suffer from cardiac disease. The coronary circulation is usually in a very healthy condition and the anticoagulation system also functions very well. But individual who is new to the altitude of 4000m does not have this kind of physiological adaptation; therefore, the complication of insufficient blood supply of cardiac muscles occurs frequently. The characteristics of this complication are the occurrence of pain under the sternum, difficulty in breathing, weakness, then dizziness, unconsciousness. If patients are not treated in time, their lives may be in danger. The ECG and autopsy report both verifies that the symptoms (of mountain sickness) are caused by the insufficient blood supply of the cardiac muscle.

The following is a summary of the general symptoms of mountain sickness:

Mild symptoms: The concentration of red blood cells reaches 7 million per cubic mm. The red blood cell/white blood cell ratio is close or over 70%. Major symptoms are fatigue, purplish skin color, headache, tiredness, waking up with suffocation during sleep, periodic breathing, mucosa congestion (lips, nose, eyes, etc.), loss of voice, indigestion, constipation, losing weight. Symptoms, such as nausea, vomiting, dizziness, degenerated vision, abnormal sensation, will develop later.

Severe symptoms: Flushy skin color during rest, purplish skin color during exercise (especially on face, ears, nose and hands), swollen and dark eye lids, nose bleeding, loss of



voice; tongue congestion; protrusion of taste buds; dry skin; sweating at forehead and hands; thick uneven finger nails, pulmonary emphysema; dragging steps while walking, extreme weakness, drowsiness; loss of appetite melancholy; indifference toward other people; dizziness; decreased vital capacity; unstable heart function; mild hypertrophy of liver (seldom); etc. It should be pointed out that the symptoms listed above may affect the same patient individually or at various times. Some of the symptoms are primary, some are induced by others, and many of them result in a chain reaction. However, the basic reason contributing to all the symptoms is the malfunction of different important organs, especially the central nervous system, the heart and the lung, due to anoxia.

The symptoms of pulmonary-emphysema-type mountain sickness:

Since pulmonary emphysema is the most common and serious symptom of mountain sickness, it is necessary to discuss more extensively this type of mountain sickness. Patients usually suffer chronic trachitis and gangrene laryngitis. The major symptoms are suffocation, purplish skin, pulmonary congestion, coughing up blood, laryngitis, malfunction of the right heart, the decrease of pulmonary air exchange volume, and the corresponding increase of  $\text{CO}_2$  partial pressure in pulmonary alveoli, the decrease of  $\text{O}_2$  saturation degree in the arterial blood. The pulmonary emphysema usually occurs above 3000m elevation. The early symptoms of pulmonary emphysema are prolonged fatigue, difficulty in breathing (within 1-2 days), coughing (within 1-2 days). The secondary symptoms are greater breathing difficulty, coughing up blood, noise in the lung, low blood pressure, increased heart beat, purplish color are occasionally found among patients. All these described symptoms can be improved or completely relieved after the patients return to the plains for a period of time, but will reoccur if

the patient is exposed to high altitudes again. Patients are especially prone to suffer pulmonary emphysema again when re-exposed to high altitudes.

## VII. Prevention of anoxia

### A. Adjustment of the inhaled air

The most basic and direct method to avoid anoxia is to adjust the pressure and composition of inhaled air. One of the basic measures is to supplement  $O_2$ . In air or space travel, the compressed air is either supplied alone or with pure  $O_2$  together. For safety and comfort reasons, the  $O_2$  content and the pressure of the inhaled air above 3000m elevation should be maintained at the same level as those at sea level. At an altitude above 12,000m, the compressed oxygen has to be supplied in order to meet the physiological  $O_2$  need. It is necessary to fully understand the required concentration and pressure of  $O_2$  while supplying the  $O_2$ . Two approaches are introduced as follows:

(1) Table 3-8 shows the  $O_2$  concentration required to keep a constant  $O_2$  partial pressure at various altitudes (from 3000 to 12,000m).

(2) Figure 3-12 indicates the inhaled air pressure required to keep pulmonary  $O_2$  pressure between 120-141mmHg at various altitudes.

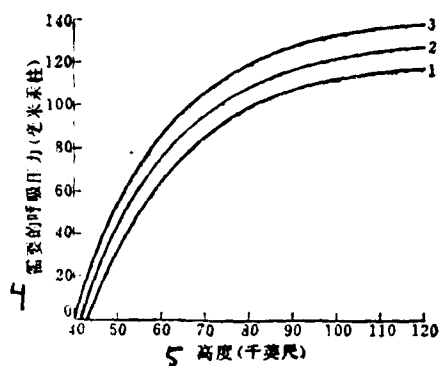


Figure 3-12. At different altitudes, the inhaled air pressure required to maintain certain level of absolute pressure in the lung.

Key: 1. lung pressure 120mmHg, 2. lung pressure 130mmHg, 3. lung pressure 141mmHg, 4. inhaled air pressure required (mmHg), 5. Elevation (1000ft).

TABLE 3-8 The correlation between altitude and the requirement of  $O_2$  concentration

Flying altitude (1000m)	Required equivalent altitude					
	sea level	1Km	2Km	3Km	4Km	5Km
0	21					
1	25	21				
2	28	24	21			
3	33	29	24	21		
4	37	33	28	24	21	
5	44	38	32	28	24	21
6	50	45	38	32	28	25
7	60	52	45	39	34	28
8	71	60	53	46	40	34
9	85	73	63	55	48	41
10	100	87	77	67	58	50
11	(10Km)	(10.6Km)	98	83	72	63
12			(11.2Km)	(11.8Km)	90	78
13					(12.4Km)	100
						(13Km)

Note: The figures in the parenthesis indicate the flying altitude which requires a supplement of pure  $O_2$ . Above this altitude, compressed oxygen has to be used in order to keep the  $O_2$  partial pressure of the inhaled air as required.

In order to prevent impairment of normal physiological functions caused by inhalation of compressed air, certain anti-compression measures should be taken. Even with these measures, the application of compressed oxygen still causes discomfort, let alone the unlimited toleration. The application of compressed  $O_2$  will cause a faster heart beat, further elevated pressure difference (pressure difference referred to the difference between the inhaled air pressure and the surrounding atmospheric pressure), and eventually shock or fainting.

If the pressure difference is too large, the individual will show discomfort and circulatory impairment during the early stage of the application of compressed oxygen. The symptoms of the respiratory system are uncomfortable and difficult breathing (especially when the pressure difference is over 25mmHg), which can be overcome gradually by adaptation and training. The pressure difference should be increased gradually during the training. For example, in order to smoothly reach the stage of a pressure difference greater than 25mmHg, the training procedure should be divided into 5-7 stages, each in 10-15 min. interval.

The best relief for the uncomfortable symptoms of anoxia is to supply oxygen. But the "negative effect of  $O_2$  supplementation", the aggravation of symptoms during emergency treatments under serious anoxia, has to be carefully watched

in the first few minutes. Symptoms of this "negative effect" can be as serious as convulsions or loss of consciousness for 30 seconds, but fortunately these symptoms will soon be relieved. It has been reported that at an altitude above 6000m, the sudden supply of  $O_2$  after the individuals inhale the surrounding air for 4-5 min. will cause various symptoms to individuals who are over 50 years old: 25% of them show more mistakes in their writings, 15% of them show blur vision, dizziness and nausea. The study of the coronary system indicates decreased arterial blood pressure after 2-4 seconds of  $O_2$  supply, which drops to the lowest level at 30 seconds, and will not recover until 60-70 seconds. The blood flow at the forearm speeds up accordingly.

If the duration of  $O_2$  supply lasts for several days, the  $O_2$  partial pressure should be kept under 160mmHg, unless the surrounding atmospheric pressure is lower than 1 atm. The  $O_2$  partial pressure should be kept under 180mmHg, if pure oxygen has to be supplied for more than 5 consecutive days. If the duration of  $O_2$  supplementation is not too long, the  $O_2$  partial pressure can be a little higher, but never over 1 atm. In order to prevent mild  $O_2$  toxication, pure  $O_2$  pressure should not be over 380mmHg if the exposure time is over 3 hours.

The increase of the  $CO_2$  content in inhaled air can also relieve the symptoms of anoxia which is due to the stimulation effect of higher  $CO_2$  concentration in the blood on the respiratory center. The increase of the  $CO_2$  content can excite the function of the respiratory center, further increase the frequency and depth of respiration pulmonary air exchange volume, the  $O_2$  partial pressure in pulmonary alveolus and  $O_2$  saturation degree of arterial blood, and eventually relieve the symptoms of anoxia. The  $CO_2$  concentration commonly used

is 3-5%, or not over 35mmHg, to avoid CO<sub>2</sub> toxication. The effect of increased CO<sub>2</sub> concentration (in inhaled air) on O<sub>2</sub> saturation degree of arterial blood is shown in Figure 3-13.

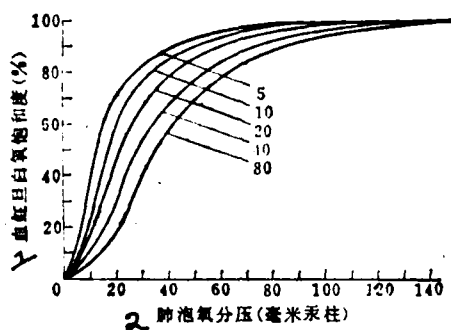


Figure 3-13. The effect of CO<sub>2</sub> partial pressure (values on the curves, mmHg) in pulmonary alveolus on the O<sub>2</sub> saturation degree of hemoglobin.

Key: 1. O<sub>2</sub> saturation degree of homoglobin (%), 2. O<sub>2</sub> partial pressure (mmHg) in pulmonary alveolus.

It is necessary to discuss more extensively the closed cabins used in the air and space travel, which is the most effective preventive measure against low pressure and anoxia.

The air pressure and O<sub>2</sub> concentration can be kept at the same level as at the sea level in a closed cabin. However, the whole closed cabin system will add extra weight to the airplane and spacecraft, and may cause even more dangers if leakage ever happens.

In order to prevent the possible dangerous accident of explosive decompression caused by the malfunction of a closed cabin, the pressure inside the closed cabin should be kept close to that outside the cabin within a tolerable range.

The astronaut suit can also be worn during the flight to prevent danger resulting from leakage, but it will surely cause inconvenience and discomfort.

#### B. Diet and drug prevention

It was discovered in the 30's that the increase of blood sugar can improve the endurance to  $O_2$  shortage in animals. It has also been reported in human beings. For example, the elevation of blood sugar level due to the oral administration of glucose can improve endurance ability to certain degree. Further studies also indicate that a high-carbohydrate diet will relieve physiological symptoms of anoxia. However, a high-carbohydrate diet will increase the secretion of insulin and speed up the consumption of carbohydrate, further lower the blood sugar level, and result in a negative effect on endurance ability, which is the disadvantage of this prevention method. In addition to that, the intake of a high carbohydrate diet may very well cut down the protein and lipid intake, which will result in nutrition imbalance. It is suggested that the high-carbohydrate diet can be used as an emergency treatment for improving endurance ability, but the long-term effect of this diet treatment still remains doubtful.

Adrenaline, diuretic and other central nervous system drugs have been tested for preventing anoxia, but all the results are not very positive.

The transfusion of a large quantity of saline solution and other fluids to decrease the blood viscosity has also been suggested, but it can only be used during the emergency measure of acute anoxia and its effect is only temporary.

## C. Selection and Training

### 1. Selection

Selecting individuals with better endurance of  $O_2$  shortage as pilot or astronaut is one of the preventive measures. Among the selection criteria, it has to be emphasized that adaptation ability and endurance ability to acute  $O_2$  shortage are two different criteria. Therefore, different selection methods should be used for these two different criteria. The test of endurance to acute  $O_2$  shortage can be performed in a decompressed chamber, but there is no effective method for determining the adaptation ability so far. Both the decompressed chamber method and mountain climbing method are time-consuming; therefore, there is not significance in using either method in selection. Nevertheless, the adaptation ability to  $O_2$  shortage during flight and space training can help to make the selection.

### 2. Physical training

Regular physical training, especially extensive exercise training, can improve the endurance ability to  $O_2$  shortage. It is reported that regular athletic training can improve endurance to 1000 ft higher in altitude, but this improvement will gradually disappear as the training is interrupted. A better physical training is hiking which shows better and more practical results than any other exercise.



## Chapter 12      CAISSON DISEASE

### I. Introduction

Although the atmosphere exists as high as 1000,000 Km in altitude, 99% of the atmosphere centers within the 32 Km radius around the earth's surface. It has been discussed in the previous chapter that the atmospheric pressure decreases as the elevation increases, and the atmospheric pressure in outer space is close to a vacuum. The change of atmospheric pressure at various elevations was shown in Figure 3-1, and the pressure difference and the comparison of the air pressure inside and outside the cabin at various flying altitudes is also shown in Figure 3-14.

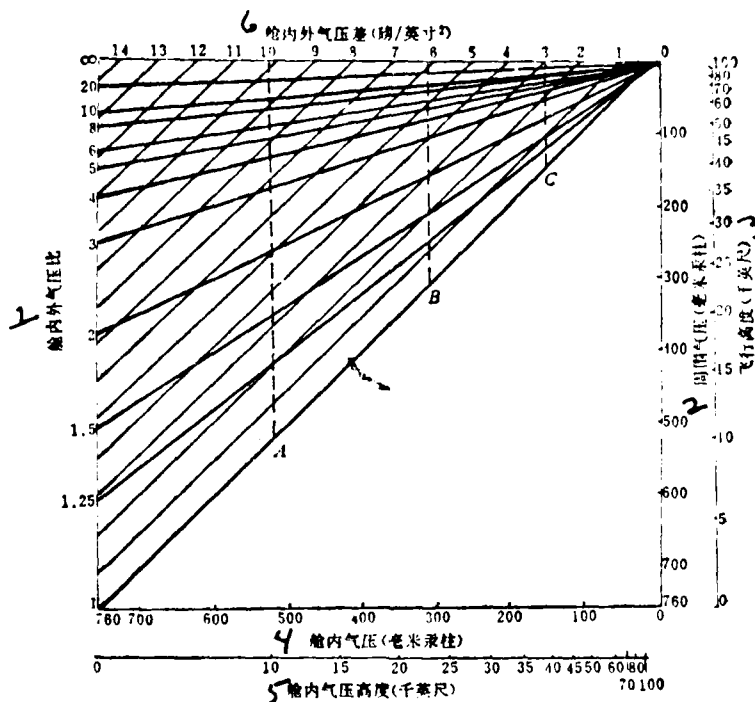


Figure 3-14. The atmospheric pressure difference and air pressure ratio inside- and outside-the-cabin at various flying altitudes.

Key: 1. the air pressure inside the cabin/the air pressure outside the cabin, 2. flying height (1000 ft), 3. surrounding atmospheric pressure (mmHg), 4. air pressure inside the cabin (mmHg), 5. corresponding altitude inside the cabin (1000 ft).

6. The pressure difference inside-and outside- the cabin (lb./in<sup>2</sup>)

A drastic decrease of pressure is harmful to the human body. If the pressure drops drastically to a certain degree, it will cause Caisson Disease. Caisson disease and anoxia are two completely different sicknesses. The latter has been extensively discussed in the previous chapter. The causal factors of caisson disease will be extensively discussed in the following chapter. In this section, we will only generally introduce caisson disease to give the readers a background for further study.

When the human body is suddenly exposed to an environment of low atmospheric pressure, the gases dissolved in the

tissues and the body fluid will rapidly and massively leave these tissues. If these released gases cannot be exhaled from the lungs immediately, they will form bubbles inside the body. These bubbles will aggregate at certain areas in the tissues and the body fluid, which will press against the nerve endings and cause pain. If the bubbles block the blood vessels, it will cause local histological anoxia. If the blocked areas happen to be vital organs, it may even cause mortality. There are some other minor causal factors of caisson disease, which will not be discussed in this section. The disease mechanisms of caisson disease and hypobarometric anoxia (anoxia caused by low atmospheric pressure) are completely different, as shown in the previous discussion.

The sudden exposure to 9000m elevation will inevitably cause the incidence of caisson disease if no preventive measures are taken. Caisson disease usually occurs at altitudes above 9000m. Therefore, it does not affect regular air travel, but causes problems to space travel and outer-space flights.

Caisson disease can result from a drop of atmospheric pressure from above 1 atm to below 1 atm, and also from several atms to 1 atm. The former is called the high-altitude type of caisson disease. The latter case happens more frequently to divers if they do not follow the safe procedures of returning to the water surface. Therefore, it is always called the diver's caisson disease. Although the symptoms vary among individuals, the diver's type is usually more serious. However, since the disease mechanism is basically the same for both types, both are called together caisson disease. The caisson disease discussed here is mainly the high-altitude type, but we also refer to some medical data about the diver's

type in order to make this topic more clear to the readers.

The most common and mild symptom is pain in the joints, namely "the bends". Therefore, divers and outer-space pilots always call caisson disease the "bends". However, the bends is not the only symptom of the caisson disease: therefore, it is not adequate to call the caisson disease the "bends". Caisson disease is first found in divers, so it is also known as the diver's sickness. However, since this sickness also occurs in pilots, it is more adequate to use the term caisson disease than diver's sickness.

## II. The disease mechanism of caisson disease

The disease mechanism of caisson disease is not completely understood yet. But it is well accepted by most research groups that the bubbles formed inside the body are the main cause of caisson disease. Of course, other reasons, such as the body gas expansion, should also be considered.

It was reported, even as early as in 1670, that a bubble was found in the eyes of a viper under low atmospheric pressure. Not until several centuries later was the bubble considered one of the main causes for caisson disease. Living under 1 atm, an individual inhales the various gases in the atmosphere, of which 79% is nitrogen. The inhaled gases then dissolve in the body fluid and tissue. When the atmospheric pressure drops, part of the dissolved gases will leave the blood and be exhaled from the lung. If the pressure drop is sudden and drastic, the released gas will not be expelled, in time, from the lung, which will act together to form bubbles.

In order to understand why the bubble is formed when

atmospheric pressure is changed, we should explore the biophysical aspect of bubble formation in the body.

In which direction the idle gases move depends mainly on the difference between the surrounding pressure ( $P_s$ ) and the gas tensile force inside the tissue ( $P_T$ ), namely  $\Delta P$ .

The pressure difference between the surroundings and tissue ( $\Delta P$ ) = surrounding pressure ( $P_s$ ) - gas tensile force inside the tissue ( $P_T$ ) (3)

$\Delta P < 0$ , not saturated

$\Delta P > 0$ , over-saturated

The bubble can be formed as  $\Delta P$  is greater than a certain value.

The rate of bubble formation shows a close relationship with the gas flux between the bubble and the tissue. The gas flux  $J$  can be calculated as follows:

$$\text{Gas Flux } J = \text{surface area of the pulmonary alveolus } A \times (\text{pressure inside the pulmonary alveolus } P_A - \text{gas surface tension in the tissue } P_T) \quad (4)$$

If  $P_T > P_A$ , gas diffuses into the tissue.

If  $P_T < P_A$ , gas leaves the tissue and diffuses into the pulmonary alveolus.

The gas pressure inside the pulmonary alveolus  $P_A$  can be calculated as follows:

$$\text{Gas pressure inside the pulmonary alveolus } P_A = \text{surrounding pressure } P_S + (2 \times \text{liquid surface tension } \gamma) / \text{radius of the pulmonary alveolus } r + \text{pressure for tissue deformation } P \quad (5)$$

When  $P_T$  is greater than  $P_S$ , this does not guarantee the formation of bubbles. In order for bubbles to form,  $P_T$  should be greater than the sum of  $P_S$ ,  $\left(\frac{2\gamma}{r}\right)$  and  $P$ .

According to the theoretical calculation,  $\Delta P$  triggers the release of gas from the body, but, in reality, the release of the dissolved gases from the tissue will not reach a significant level unless the value of  $\Delta P$  is very large. (This is only limited to the situation where there are no impurities.) However, the impurities in the human body, along with other factors, such as vibration, radiation, chemical reactions of the solvents, exercise, temperature and micro-bubbles, will induce the formation of bubbles. Therefore, it is possible for bubbles to form even when  $\Delta P = 1 \text{ atm}$ .

The main source of gas for bubble formation is nitrogen dissolved in the human body. The inhaled air is mainly composed of nitrogen, oxygen and carbon dioxide. More than 99% of the  $O_2$  and  $CO_2$  in the

blood combine chemically with the hemoglobin and the buffering substance. Only a small portion (less than 1%) is dissolved directly into the blood and the body fluid. Nitrogen cannot be utilized by the human body. Besides, its solubility in the blood and tissue is very high. Both factors cause bubbles to form during recompression. The nitrogen partial pressure at sea level is 593 mm Hg, and that at the pulmonary alveolus is 570 mm Hg. Under this circumstance, the solubility of  $N_2$  in the blood is 1.5-1.7 ml/100 ml. Assuming that the total blood volume is 5500 ml, then the total amount of nitrogen dissolved in the blood is approximately 800-900 ml. In addition to that, nitrogen also dissolves in other body fluid, tissue fluid and the adipose tissue. This raises the total amount of nitrogen dissolved in the body to 2-3 liters. The majority of this nitrogen is stored in the adipose tissue. When the atmospheric pressure does not change significantly, the corresponding drop in nitrogen pressure will still allow the nitrogen dissolved in the tissue and blood to escape from the lung. In the contrary, the drastic decrease of nitrogen content in the atmosphere will not allow the nitrogen to escape from the lung. Furthermore, it causes the bubbles to be formed in the tissue and the blood. The formation of the bubbles results in caisson disease.

The following factors will accelerate the formation of bubbles:

- (1) Vibration, exercise, effect of ultrasound.
- (2) The existence of micro-bubbles in the body fluid and other impurities, especially the emulsified lipid particles.
- (3) Low viscosity of the body fluid, which results in a slower flowing rate.
- (4) Fever.
- (5) Higher concentration of dissolved gaseous content (especially nitrogen).

The physiological effects of the formation of bubbles inside the body can be categorized into two kinds: mechanical and physiological-biochemical effects. These two effects are correlated and

complementary, just like two different views of the same object. They cannot be completely differentiated from each other. The mechanical effect varies according to the locations of the bubbles. If the bubble occurs inside the cell, it will cause cytolysis and malfunction of the cells. The bubbles found in the tissue and the body fluid can cause the "bends", release of enzymes and thrombosis. The bubbles formed outside the blood vessels may press the blood vessels and the nerves to cause pain. The bubbles formed inside the blood vessels will cause thrombosis, further circulatory impairment, blood clotting, insufficient oxygen and blood supply in tissue, edema, or hemorrhage, which will threaten the patient's life if these symptoms prevail to the vital organs.

A chain of physiological-histochemical reactions is induced by the mechanical effect of bubble formation. For example, the surface interaction between the bubble and the blood can cause the platelet and fibrinogen to be attached to the surface of the bubble. The attachment of the platelet to the surface of the bubble will induce the release of the coagulation factor and further the formation of thrombosis. It will also trigger the release of vasoconstrictor which will increase the resistance in the peripheral circulatory system and further cause circulatory impairment. Bubbles can also stimulate early coagulation and induce disseminated intravascular coagulation and also the local release of cardio-relaxin. After the bubble contacts the blood, it will cause a change of the lipid content in the blood, and the formation of thrombosis and sclerosis. The blockages caused by the formation of bubbles, clotting, and sclerosis are interrelated, which, as a whole, will interfere with the blood circulation.

Although the formation of the bubbles is the main cause of caisson disease, it is not the only factor. The expansion of the body gas after decompression is another cause for caisson disease. There are two stages of gas expansion. The first stage is the expansion of gas inside the intestine. The second stage occurs when the gas dissolved or absorbed inside the intestine expands



or escapes. Although the gas in the stomach and intestine will cause discomfort, it is not the major symptom of caisson disease. It does affect flight efficiency, but does not threaten the health and the life of the patient.

The sinus (e.g. nasal sinus), the cavity (e.g. dental cavity), and the tract system (e.g. respiratory tract, lung, etc.) will also be affected by gas expansion. The expansion of the pulmonary alveolus will impair the exhalation of the gas, which deserves more attention.

### III. The Physiological Effect and Clinical Symptoms of Depression

The clinical symptoms and physiological effects of decompression are mainly caused by the formation of bubbles inside the body. Some secondary symptoms of gas expansion have been discussed in the previous text, therefore, only the primary clinical symptoms will be discussed here.

#### 1. Pain in the joint and extremities.

The "bends" is the most typical symptom of caisson disease which usually occurs at the extremity joints. Patients first experience mild discomfort, and then suffer sharp pain. The most commonly affected areas are knee joints and upper extremities. Pain at the hip joint is seldom experienced. The occurrence of early pain will usually force the patient to do some exercise which, however, will only aggravate the pain. The pain can occur at several spots of the body, as shown in Figure 3-15.

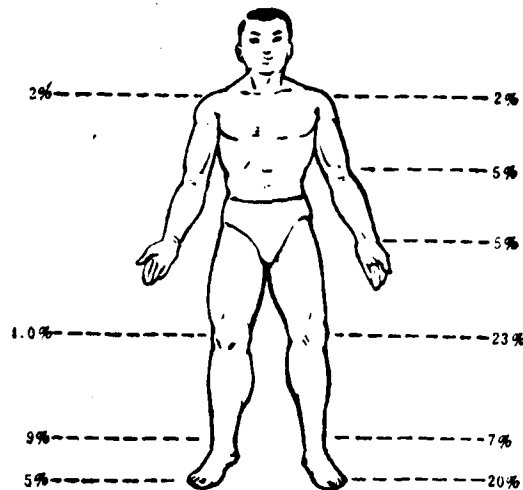


Figure 3-15. The joint which suffers pain. (The percentage indicates the incident rate.)

## 2. Respiratory symptoms.

The respiratory symptoms result from bubble formation and gas expansion. The bubbles formed during decompression travel to the lungs through the blood. At the beginning, the pulmonary alveolus can handle most of the bubbles, but after long duration, pulmonary circulatory impairment occurs due to the lipid deposit, which will result in pulmonary cramp. The intensity built up in the lung, along with the gas expansion in the lungs and the emphysema, will cause many clinical symptoms in the respiratory system. Patients first feel pressure in the lower thoracic area and the upper abdomen area, and difficulty in inhalation during deep breath. Patients occasionally suffer pain and pressure under the sternum and general discomfort. As the duration prolongs, coughs will occur whenever patients try to take a deep breath, the pain under the sternum will aggravate, breathing will be short and shallow, and the patients further develop difficulty in breath-

ing, eventually choking and shock.

Gas expansion in the lungs during decompression is a dangerous factor, especially during diving. For example, when the diver ascends from 30m under the sea (approximately 4 atm) to sea level, if gas in the lungs cannot be expelled, the volume of the lung will be expanded 4 times the normal size. Therefore, continuous exhalation under decompression is very important to the safety of the diver. It is also important in the case of drastic loss of altitude during flight.

### 3. The symptoms in cardiovascular system.

Thrombosis will cause impairment in the circulation, slow heart beat, and decreased cardiac output. The impairment of cardiovascular circulation will result in cardiac failure, decreased arterial blood pressure, and elevated venous blood pressure. Local circulatory impairment will also cause local tissue damage due to the shortage of oxygen and blood supply. If this occurs in the central nervous system, severe nervous symptoms will appear. If bubbles stay in the lymph system, it will cause blockage in the lymph system and swollen lymphonodus.

### 4. Blood.

The most common symptoms are clotting, vascular thrombosis, elevated hemoglobin level, elevated lipid acid level in the plasma, prolonged prothrombin time, decreased platelet count, decreased corticosterone content in the plasma, decreased serum lactate level, a shortened englobulin lysis time, etc. It is also found that the platelet reticular cells, thrombosis index no., the coagulation ability of the platelet are increased. The activity of the serum sodium and anti-clot factor III drops significantly.

## 5. The skin.

Chilling feeling occurs on the skin and the thigh during decompression. Temporary rash, purple spot, itchiness are also reported. Local urticaria, swelling, edema, pain, especially in the thorax are occasionally found. Difficult breathing and burning are always associated with the above symptoms.

## 6. The gas expansion in the digestive system and the sinus cavity.

The gas expansion in the digestive system always results in abdominal pain which may be relieved by the release of gas from the cardia and anus. Occasionally, the pressure exerted on the intestinal muscle by the gas expansion can cause a local shortage of blood supply and impaired intestinal activity. Meanwhile, the feeling of intestinal tympanites, elevated diaphragm, and abdominal pain will be aggravated temporarily. Some patients suffer a bursting pain caused by gas expansion inside the sinus cavity.

## 7. The inner ear and vestibule.

A series of symptoms, such as the temporary loss of hearing, buzzing in the ears, are induced by the pressure imbalance outside and inside the eardrum. Some serious symptoms, such as broken eardrum and drastic pain in the inner ear, may also occur. The vestibular reflexes, such as nausea, vomiting, dizziness, may appear. These symptoms may be more serious and can occur readily in patients with history of sinusitis and tympanites. If an individual keeps on swallowing saliva during decompression, some of these symptoms may not occur. That is the reason why passengers are always encouraged to chew on some candies to avoid discomfort in the inner ear during the take-off and landing.

## 8. Vision.

Bubbles in the eyes will cause blurred vision and retrogression of vision, which are usually accompanied by headaches.

9. Symptoms in the nervous system.

The major symptoms are headache, insomnia, fatigue and collapse. Some other symptoms, such as paralysis, abnormal sensations, spinal injury and symptoms caused by cerebral thrombosis, may occasionally occur.

10. Toothaches at high elevation.

It is usually induced by the latent pulpitis, but also, occasionally, by some other factors. The characteristics of the toothache are that the pain will gradually spread out to the neighboring teeth and jaw.

11. Flying ability.

Control efficiency will be affected by caisson disease at altitudes above 9000 m, no matter whether the oxygen is sufficiently supplied or not. When descending to an altitude of 9000 m, some individuals cannot hear the alarm and cannot manipulate the control panel properly. It is occasionally reported that murmuring, flush, increased pulse rate (150-180 times/min), unconsciousness, cramps, droop of the head, and low-frequency waves in the EEG may occur above 12000 m elevation.

The correlation between atmospheric pressure and voice loudness is shown in Figure 3-16. It indicates that, at high altitudes, and low-pressure environment, the intensity of the voice will decrease as the atmospheric pressure drops, which can cause a communication difficulty.

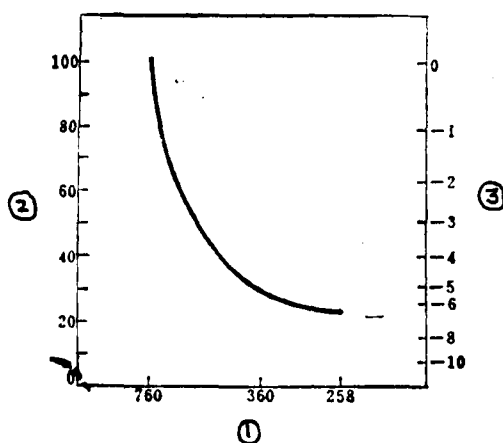


Figure 3-16. The intensity of the voice decreases as the atmospheric pressure drops.

Key: 1 - surrounding atmospheric pressure (mm Hg)

2 - relative efficiency of voice (%) (compared with that under 1 atm)

3 - relative efficiency of voice (decibel) (compared with the value under 1 atm)

### 12. Vaporization.

Another important physiological effect of low atmospheric pressure is a drastic increase in the water vaporization, which will cause a tremendous loss of body heat. For example, the speed of vaporization at 1 atm is 45g/hr. at rest, 150g/hrs during mild exercise (climbing a ladder of 1 m height at a speed of 12 times/min for 20 min, metabolic rate is 150 Kcal/hr). At an altitude of 10 km, and a surrounding temperature of 12-23 C, the vaporization rate at rest increases to 90-110 g/hr, and that during mild exercise increases to 260 g/hr. The drastic increase of vaporization can cause the skin temperature to drop 1.4-2.5°C in 2 hrs., which will result in a chilly feeling. The faster the decompression occurs, the more chilly one will feel. The rate of body heat loss increases significantly from 12 km elevation up, and will increase

even more drastically as the elevation increases. If the rate of water loss is kept under 1500g per hour, or the total water loss is maintained at less than 10% of the body wt., there will be no serious danger. Since the vaporization rate at high altitudes is far below this value, there will be no threat caused by vaporization. However, the chilly feeling and lower skin temperature caused by vaporization do affect the efficiency of manipulation.

### 13. Shock of fainting.

There are two major types:

#### (a) Primary shock.

Usually, there are no other serious symptoms for this kind of patient. Patients suffer discomfort, fever, chill, sweating at the palms and forehead, paleness, chill at distal ends of the extremities before the shock. Nausea and a weak pulse rate frequently occur. Within a few seconds, unconsciousness will appear.

#### (b) Secondary shock.

This type of shock is induced by the further development of other serious symptoms, such as the "bends", choking, excessive gas in the abdomen, and symptoms in the nervous system.

Many symptoms of caisson disease, including shock, will disappear after the pressure increases. However, exceptions do exist. The symptoms of some patients will not be relieved in a short period of time or even be aggravated by the increase of atmospheric pressure. Therefore, medical personnel have to closely watch the patient for this possibility, although it seldom occurs.

In addition to primary symptoms, patients will occasionally suffer some complications and aftereffects. The most common after-

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effects are: (1) the impairment of peripheral circulation which occurs in a few hours after the pressure is elevated (2) the sudden occurrence of a weak pulse, low blood pressure, increased blood viscosity, shock, and even death if patients are not treated properly after a few hours. (3) collapse accompanied by a nervous-type paralysis, unconsciousness, or death. Patients always suffer the aftereffects, such as numbness or paralysis of the extremities. Therefore, a patient has to be closely watched for 1 day after the emergency treatment.

Several typical symptoms, such as anxiety, headache, paleness, sweating at the extremities, will occur before the after-decompression shock. The general or intensive nervous symptoms, such as weakness and cramps, can occur significantly, and result in prolonged deep slumber and collapse. These patients suffer fever as an early stage symptom.

It has been reported in other countries that the incidence of shock after drastic decompression is 400 cases/1 million cases (serious cases: 150) above 9000 m elevation. For some rare cases, pilots showed no symptoms of shock during flight, but serious symptoms after landing.

Caisson disease can be categorized into two types according to its clinical symptoms:

Type I, simple painful symptoms, namely the "bends":

The pain usually occurs at the joints. This type comprises 75-80% of the total caisson disease cases. It represents a mild-type of caisson disease, and usually does not have aftereffects.

Type II, over-all type:

Pain of the joints is only one of the symptoms. Visual symptoms, occasionally accompanied by difficulty of breathing, collapse, paralysis, usually occur before the joint pain. Type



Type II represents the more serious cases. The symptoms usually last for a long period after the decompression, and remain even after the bubble disappears. In the more serious cases, patients suffer permanent aftereffects, such as numb limbs and paralysis.

Frequently, there will be a latent period before the decompression symptoms occur. The decompression symptoms usually occur 5-10 minutes after the critical elevation is reached. The correlation between the exposure duration and the patient number can be graphed into a "Q" curve. The latent period can be as long as 2½ hrs.

The short-term effect of the decompression has been described as above. What about the long-term effect of the decompression? Not too many studies have been done on this subject. In the following text, 2 cases of the long-term effect of decompression will be discussed.

(1) Staying at an altitude of 3000, 5000, 7000 m. (The O<sub>2</sub> partial pressure is kept at 150-200 mm Hg):

The pulse rate increases by 10-15 times/min on the 14-15th day. The function of the cardiovascular system is enhanced by 10-15% on the 10th-15th day, and even to 50% later. The concentration of plasma albumin increases by 12%.

(2) Staying for 62 days at an atmospheric pressure of 308 mm Hg (normal O<sub>2</sub> partial pressure):

The major symptoms are: the functions of the cerebral cortex and the cardiovascular system are inhibited.

The most common symptoms of caisson disease, summarized in 2 categories, are shown in Table 3-9. The incidence rate of these symptoms at high altitudes is listed in Table 3-10, which indicates the importance of preventing caisson disease in aeromedical practice.

The occurrence of caisson disease is more frequently found among the fighter pilots.

TABLE 3-3 The categorized clinical symptoms of caisson disease

(1) Acute

TYPE I

Limbs

pain, the "bends"  
numbness and paralysis  
abnormal sensation  
weakness and fatigue  
edema

Skin

mottle  
edema  
rashes  
fever  
sweating

TYPE II

Heart, respiration

pain under sternum  
cough  
choke  
belch  
faster respiration rate (animal)  
disturbed circulation (paleness,  
dizziness, nausea)  
chock  
increased concentration of heme  
aggregation of platelet and ery-  
throcytes

Nervous system

unconsciousness  
headache  
loss of coordination  
dizziness and disorientation  
degenerated hearing ability  
talking nonsense  
  
murmuring  
spinal damage  
sensory and motor paralysis

(2) Chronic

bone gangrene  
(not bacterial)

central nervous system  
damage

paralysis caused  
by spinal damage

### (3) Damage caused by the gaseous obstruction

note: The study of 73 cases: unconsciousness (21), dizziness (10), pain in thorax (9), abnormal sensation (2), cramp (6), paralysis (5), nausea (3), visual symptoms (3), headache (2), pain in the abdomen (1), pain in the knee (1), insanity (1), pressure in the thorax (1), loss of the taste sensation (1).

TABLE 3-10 The incidence rate of the decompression symptoms at different altitudes (1)

Symptoms	Staying at 8400 m for 2 hrs.	Staying at 11400 m for 2 hrs.
the "bends"	73.9	56.5
belch	4.5	6.5
sensation (skin)	7.0	1.6
visual symptoms	2.0	4.8
symptoms of central nervous system	1.0	0
collapse	9.0	25.8
others	2.5	4.8

### IV Endurance of Decompression

Three well-accepted criteria are discussed as follows:

(1) The first appearance of caisson disease as the indicator: This criterion can be used as the safety margin for pilots and passengers. It is difficult to meet this criterion under bottle conditions.

(2),(3) The other 2 criteria are associated with the case when the major symptoms of decompression reach intolerable levels, and major physiological impairment occurs. Generally speaking, the occurrence of the previous two situations will have a detrimental effect on the flying and fighting ability. Damage can be caused if these two limits are exceeded. Therefore, these 2 criteria can be considered as the minimum flying safety standard.

(1) The first appearance of caisson disease as indicator:

The correlation between flight altitude and the incidence of caisson disease is shown in Figure 3-17. Generally speaking, the symptoms of caisson disease will start to show when the pressure drops to half of the original value. Our data indicates that caisson disease seldom occurs at 3000-5400 m elevation, and rarely at 5500-7000 m elevation and most of the cases reported are not very serious. In other words, 7000 m can be considered as a safe altitude to most of the individuals. The majority of the caisson disease cases occur above 9000 m elevation. Therefore, it is considered as the critical elevation of caisson disease.

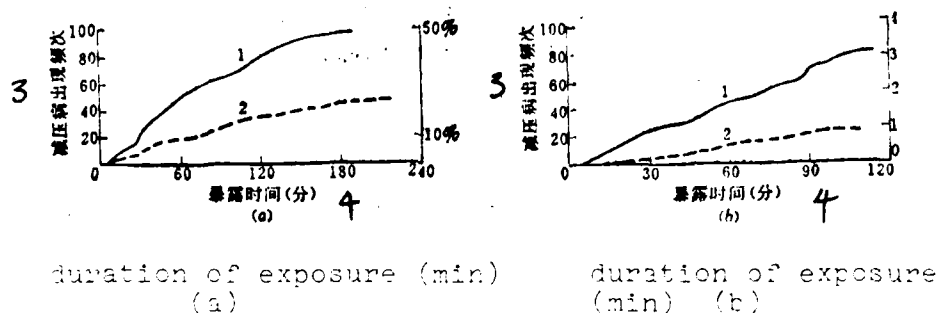


Figure 3-17 The correlation between the incidence of caisson disease, altitude and the duration of exposure.

(a) altitude: 35000 ft., duration of exposure: 4 hrs.

(b) altitude: 28000 ft., duration of exposure: 2 hrs.

Key: 1 - the occurrence rate of the symptoms of caisson disease (Figure on the left, Y-axis)  
 2 - the occurrence rate of malfunctions (1) (Figure on the right, Y-axis)  
 1 - incidence of caisson disease  
 1 - duration of exposure (min) (b)

TABLE 3-11 Tolerance to decompression

Condition	Percentage of individuals requesting returning to the original pressure (%)
11 km, - hrs.	
12 km, - hrs.	45
13 km, 1 hr.	21
12 km, 1 hr.	20
9 km, 1 hr., 12 km, 1 hr.	11
9 km, 2 hrs., 9 km, 2 hrs.	6
	1.65

(12) Reaching the tolerable limit as indicator:

Most people can tolerate an altitude below 9000 m for at least 1-2 hours. About 20% of the population cannot stand 11-12 km elevation even for 1-2 hours. Almost half of the population cannot stand 12,400 m for more than 4 hours.

(13) The appearance of physiological disturbance as indicator:

Some data on physiological disturbance caused by decompression are shown in Figure 3-18. The nitrogen bubble can appear when atmospheric pressure drops to 141 mm Hg (corresponding elevation: 12 km). If the pressure difference inside and outside the ears exceed 180 mm Hg, the ear drum will be damaged.

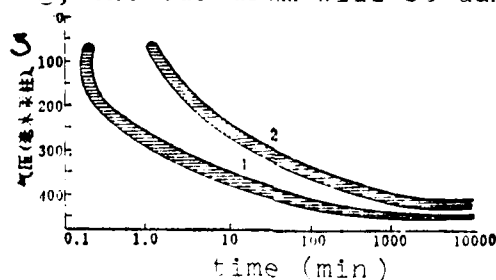


Figure 3-18 Endurance of decompression.

Key: 1 - effective consciousness time  
2 - estimated reversible unconsciousness time  
3 - atmospheric pressure (mm Hg)

Staying at 10.5-12 km for 1 hour can cause 8-13% of the individuals to lose working ability. Staying at this altitude for 2 hours can cause 20% to lose their working ability. Half of the group will lose their working ability if they stay at this altitude for 4 hours. Therefore, in order to keep the safety and minimum working ability of the majority, the atmospheric pressure in the cabin has to be kept, at least, the same as that of 10,500 m elevation when the travelling time is more than one hour. However, 1-15 of the passengers will still show some physiological disability when traveling at 7.5-9 km for more than 2 hours. For most of the passenger flights, the pressure inside the cabin is always kept at the level of 7000-8000 ft. elevation to insure the safety of the majority of the passengers.

Some important factors which affect the endurance ability of decompression are discussed as follows:

(1) Rate of decompression:

The faster the decompression occurs, the higher the incidence rate of caisson disease is. The seriousness of the symptoms also depends on how fast the decompression happens. If the decompression happens more slowly than that of the gas release in the tissue, it can be tolerated. It has been proven that an individual will not suffer caisson disease if the rate of elevation gain is less than 30-3000 m/min. The most efficient prevention for caisson disease is to keep the rate of elevation gain under this figure. In the case of fighter planes, it is easy to exceed this limit. Therefore, for the safety of the flight crew, compressed air is always supplemented.

(2) The original atmospheric pressure and gas saturation in the body:

The original atmospheric pressure before decompression decides the pressure of the dissolved gas in the tissue. The duration at the original atmospheric pressure decides the saturation degree of the idle gases dissolved in the body. The higher original atmos-

pheric pressure will result in a higher saturation degree of solubility and more serious over-saturation during decompression. Therefore, it is more dangerous to ascend from the deep than from the shallow of the waters. For the same reason, an individual who takes off on a plane right after diving, will suffer caisson disease at lower altitudes than those who did not dive before the flight. Caisson diseases during flight and diving are different in the way the pressure change: For flight: the pressure changes from several atms to 1 atm. Therefore, the rate of decompression and the seriousness of the symptoms are different for each individual case. The occurrence of caisson disease during flight is usually less serious and less frequent.

(3) Age:

The research data indicate that, between 12-28 years of age, the relative sensitivity to caisson disease increases about 30% for every 3 year interval. It will level off or even decrease after 30 years old.

(4) Obesity:

Under the same decompression conditions, the bubbles are easier to form and the symptoms of caisson disease are more severe for obese people. The pressure required to relieve the symptoms of caisson disease is also higher for obese people.

(5) Physical activity:

Strenuous physical activity during decompression will decrease endurance.

(6) Repeatability of decompression:

Repeating the decompression several times in 24 hours will decrease the endurance to decompression. Our data indicate that the interval between 2 consecutive decompressions should be at least over 48 hours in order to avoid the accumulative effect.

(7) Sickness and injury:

Individuals with a history of arthritis or unhealed wounds will suffer the "bends" more easily. Individuals with a history of dental problems will easily suffer toothaches during decompression. The physical weakness will cause a decrease of decompression endurance.

In addition to the previous items, other factors, such as anoxia, high temperature, supersound, weight loss, drunkenness, insomnia, and fatigue will all decrease the endurance, but adaption and training, on the other hand, will improve the endurance.

V. Preventive measures against caisson disease

A. Prevention of caisson disease

The best way to prevent caisson disease is to increase the surrounding pressure by keeping a constant atmospheric pressure in the closed cabin, or by wearing an pressurized suit. The second effective way is to decrease the dissolving of nitrogen, in the body. If caisson disease occurs, the best treatment is compression over the whole body. Patients can be placed in a compressed chamber first and then be decompressed according to the appropriate procedures.

1. Closed chamber and pressurized suit.

The most effective prevention for caisson disease is to maintain the surrounding pressure on the body surface in a tolerable range by using a compressed chamber or by a pressurized suit. Both equipments should be strictly checked to guarantee that there is no leakage. Any leakage will cause the danger of explosive decompression. In order to avoid possible danger caused by the leakage, the pressure inside the compressed chamber or the pressurized suit should be maintained in a tolerable range, as close to



the surrounding atmospheric pressure as possible. (Ref. Table 3-12)

elevation (1000 m)	19	20	22	24	26	28	30
minimum pressure requirement (mm Hg)	0	7.0	18	26.2	32.1	38.4	39.5

### 3. $O_2$ -intake denitrogenization.

Before decompression happens, the inhalation of  $O_2$  or remaining in pure- $O_2$  environment for a period of time (several hours) can force the nitrogen to be released massively from the body. Therefore, this method is called  $O_2$ -intake denitrogenization. This treatment is very helpful in relieving symptoms caused by decompression. The duration of denitrogenization cannot be too short. If denitrogenization takes place at 1 atm, the concentration of  $O_2$  has to be very high. The most efficient denitrogenization is to put patients in a cabin filled with pure oxygen. The effect of inhaling pure  $O_2$  on denitrogenization is not as good as that in the pure-oxygen environment. Decreasing the atmospheric pressure at an approximate rate and appropriately elevating the atmospheric temperature (to induce perspiration) can greatly improve denitrogenization.

Denitrogenization for 4 hours under a pure- $O_2$  environment can clean out 95% of the dissolved nitrogen in the body. If the duration of denitrogenization is less than 2 hours, the effect is not significant. How fast the denitrogenization can take place varies greatly among individuals. The rates of denitrogenization in various tissues are also different: Denitrogenization in the lung and the circulatory system occurs very fast. Denitrogenization in the adipose tissue and bone is very slow. If the pilot is denitrogenized for 50-60 minutes under the pure- $O_2$  environment, and then experiences the decompressed environment, corresponding to 7.5 km elevation, before the flight, ("bends") will hardly appear. The inhalation of pure  $O_2$  for a while before flying will

also benefit denitrogenization. However, its effect is not as good as that under the pure- $O_2$  environment. Denitrogenization will be benefited by inhalation not only before, but also during and after the decompression.

3. The replacement of nitrogen by other inert gases.

At high atmospheric pressures (e.g. in the closed cabin of airplane or air ship, or deep under the sea), nitrogen gas can be replaced by hard to-saturate inert gases (e.g. helium-oxygen gas mixtures). On the other hand, easily saturated gaseous mixtures, such as nitrogen-oxygen, neon-oxygen, argon-oxygen, should be used during decompression. From the theoretical point of view, this will effectively relieve the symptoms caused by decompression and improve the endurance, but the poisonous effect of these gases should be closely watched.

4. Isolated cabin.

In order to prevent leakage from affecting the entire cabin, design engineers once tried to divide the whole cabin into several small compartments and use gates to separate these compartments.

5. Appropriate decompression procedures.

Establishment of a set of standard decompression procedures and reasonable safety criteria for decompression is also an effective preventive measure against decompression.

The maximum altitude that the modern supersonic jets fly is between 15 and 22.5 km. For the safety of the passengers, the passenger flights are usually kept under the altitude of 7.5 km so that the leakage of the closed cabin will not cause any danger. If leakage occurs, the atmospheric pressure will suddenly drop to the pressure at 7.5 km altitude). If leakage happens, the plane

will be forced to drop to the safety altitude of 4.5 km, an elevation tolerable for most passengers, in 2 minutes. If the flying altitude is above 10.5 km, the emergency descent to 4.5 km will take more than 4 minutes which might cause irreversible brain damage to the passenger. That is the reason why the regular passenger flights are always kept below 7.5 km. After this accident happens, it is better to land or, at least, descend to 1.5 km elevation to guarantee the complete recovery of the crew members. If a passenger plane is requested to fly above 7.5 km, there should be some technical guarantee that this plane can be brought down to 4.5 km altitude within 3 minutes and 20 seconds. Although atmospheric pressure is kept at the level of 4.5 km in the closed cabin and pure  $O_2$  is provided, flying at the altitude of 15-21 km is still not safe. The effective consciousness time at this altitude is around 10 seconds, which may not even be long enough for the passengers to put on the emergency respirator masks. Therefore, the passengers may very well lose their consciousness even before the mask is put on. Any pilot flying above this altitude should be able to guarantee that he can bring the plane down to 3 km in 4 minutes and 24 seconds, to 6 km in 8.2 minutes, and to 4.5 km in 10 minutes. In other words, for the safety of the passengers, everyone has to wear resuscitators and the crew members should wear coveralls or partially-covered pressurized suits while flying above 12.3 km altitude. These kind of supersonic jets are usually equipped with the emergency air supply (e.g. oxygen bottles for supplying emergency  $O_2$  or the air is taken from the surrounding atmosphere) which will slow down the pressure drop as the leakage occurs.

The pressure inside space ships is usually kept much higher than outside the ship. Although the crew members put on the astronauts' suits, the pressure inside the suit is much lower than inside the cabin. In order to avoid the incidence of caisson disease, it is necessary to design a set of decompression procedures. Two effective decompression procedures are possible as follows:

(1) If the atmospheric pressure of the pure oxygen environment inside the cabin is  $3600 \text{ kg/m}^2$ , and that inside the suit is  $2200 \text{ kg/m}^2$ , the following decompression procedure is suggested: Before the space ship takes off, the crew members will be denitrogenized under the pure oxygen-1 atm environment for 4 hours. The pressure in the ship will then be maintained at  $3600 \text{ kg/m}^2$  (pure-oxygen) for 4 hours. After that, the crew members are ready for outdoor activities. When crew members are working outside the ship, they are under the pressure below  $2200 \text{ kg/m}^2$ . No symptom of caisson disease will appear if they stay under this pressure for 2 hours. The only disadvantage of this procedure is that the denitrogenization for 4 hours under the pure-oxygen environment at sea level can easily cause fire hazard. One way to compensate for this is to let denitrogenization take place inside the pressurized suit, instead of inside the cabin, which can relieve the danger caused by the high-pressure, pure oxygen environment.

(2) If the atmospheric pressure inside the ship is  $7000 \text{ kg/m}^2$  (nitrogen-oxygen mixture:  $\text{N}_2\text{O}_2 = 2:1$ ) before it takes off, staying under this environment for 4 hours can expell 38% of the dissolved nitrogen in the body. After the space ship takes off, the pressure inside the cabin will be kept at  $3600 \text{ kg/m}^2$  (nitrogen-oxygen mixture, 30% of oxygen). Following this procedure, a few individuals will still suffer the caisson disease. However, the increase of pressure inside the pressurized suit to  $3240 \text{ kg/m}^2$  (added to  $3600 \text{ kg/m}^2$ , the pressure inside the ship, or make the total pressure of  $6840 \text{ kg/m}^2$ ) will eliminate caisson disease completely. After a period of adaptation, the high pressure inside the suit can be slowly released. Outdoor activities cannot be allowed until a few hours after take-off.

#### 5. Adaptation and Training

The incidence of the "bends" decreases as the working hours of diver or mine worker are prolonged, which indicates that the

"bends" can be adapted to. However, the training of developing this kind of adaptation takes a long time and requires the supervision of experienced doctors and technical staff. Unless there is absolute need for this training, it is usually not recommended. However, occupational adaptation is a natural way of prevention.

### B. The pressurization treatment of caisson disease

The pressurization is an effective treatment of caisson disease especially pressurized chambers. The bubbles formed by the dissolved gases in the tissues can be reabsorbed during pressurization, which is the theoretical basis of this treatment. The standard procedures of pressurization treatment are as follows: The patient is first moved into the chamber, and the pressure inside the chamber is rapidly increased until all the symptoms disappear. After the disappearance of all the symptoms, decompress carefully and slowly, following the standard procedures until the pressure drops to normal. The pressure for treatment cannot exceed 5300 kg/m<sup>2</sup> in any case.

## Chapter 13 Dangers of Explosive Decompression

### I. Introduction

#### A. Explosive Decompression and Collision with Meteors

Explosive decompression refers to drastic decompression at an ascent rate over 1.5 km/sec. This drastic decompression makes the high-pressure gas inside the cabin expand rapidly in the same way as the gas expansion caused by an explosion. Explosive decompression usually occurs when leaks suddenly appear in the cabin. Explosive decompression in airplanes will only happen during battles, rarely during training. The explosive decompression in space ships is either caused by the structure damage or collision with a large meteor.

Particles of different sizes existing in outer-space: According to estimates, there exist thousand of small particles per cubic centimeter in outer-space: the smallest are radiation particles, the next are the smallest meteors (dust: diameter smaller than 0.035 cm; micrometeor: diameter smaller than 1 mm, mass smaller than 1 mg; small meteor: diameter around 1 cm to several centimeters). All the dusts, small meteors and micrometeors are composed of small quantities of dust, sand, metal pieces and various small metal particles. They usually weigh less than 1 gm. However, huge meteors several meters in diameter and of several tons exist in the universe. Some meteors become meteorites if they reach the surface of the earth. Although the total number of meteors in the universe is astronomical, really massive and huge meteors only compose a small portion of the whole population. Therefore, the probability of collision between a space ship and a massive meteor is very low. The relationship between the size of meteors and the possibility of collision is shown in Figure 3-19.

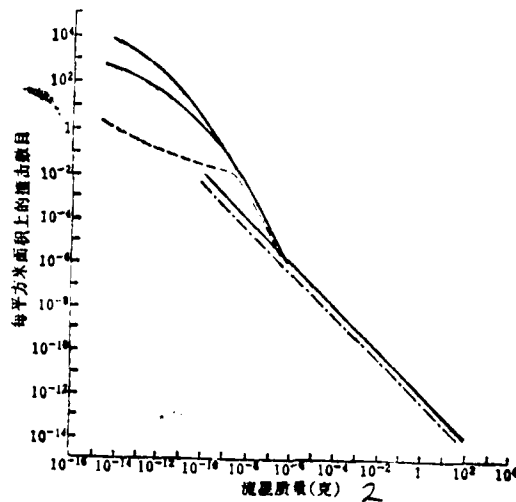


Figure 3-19 The relationship between the mass of meteors and the frequency of collision (Different curves represents different data sources).

Key: 1 - The frequency of collision  $m^2$  surface area  
2 - mass of the meteor(g)

The meteor passes through the atmosphere with great speed which results in high temperature and burning due to the friction between the meteor and air particles. The micrometeors with a diameter less than 1 mm are mostly consumed by burning up 70 Km above the Earth's surface. Only small portions of the huge meteors will drop down to the Earth to become meteorites. Less than 10% of the meteorites found on the Earth are composed of iron or iron-nickel compounds. Statistically, 5 or 6 meteorites drop on the Earth's surface every day.

Meteor clusters and their debris always travel in regular orbits in outer space. If the space ship has to pass through this orbit, the chance of collision will be increased greatly.

The high speed of meteors can cause significant damage to the space ship during collision. It has been estimated that a small 100 g rock travelling at the speed of 70 km/sec can produce the force of a 12-ton airplane travelling at the speed of 700 km/hr. Therefore, it can be concluded that a 1-mg meteor can break through an aluminum sheet of 3-mm thickness without any difficulty.

Fortunately, the meteors which are big and massive enough to penetrate the surface of the space ship are not very numerous. The problem of collision becomes a concern only when the space ship travels through the asteroid orbits. Small and light meteors, such as micrometeors with a mass less than  $10^{-7}$  g and diameter smaller than 100  $\mu$ m, can only cause scratches to the surface of the space ship, which will only affect the ship's optical surface, solar cell radiation surface and the telecommunication devices.

As for the bigger meteors (mass greater than  $10^{-7}$  g and diameter greater than 100  $\mu$ m), collisions can cause dents to the ship's surface and produce pressurized impact waves. As this wave travels to the inner-layer of the surface, it may cause local cracks and structural damage. The size of the crack is usually several times the thickness of the surface, and the crack can reach to 1/10-1/2 of the surface depth. Meteors with greater mass will penetrate through the surface. However, this kind of destructive meteor is very rare. Therefore, the meteor has not yet been a serious concern in space travel.

### B. The Estimation of Explosive Decompression

Leaks or cracks in a plane or space ship can cause the internal atmosphere to rush out. How fast the gas rushes out depends mainly on the size of the hole, but also on the internal pressure of the cabin and the cabin volume. The following equation shows the relationship between these factors:

$$t = \frac{144V}{AC} \log \frac{p_0}{p} \quad (6)$$

V: cabin volume

$p_0$ : initial pressure inside the cabin

p: pressure at any time

A: area of the hole

t: the time required for the internal pressure to drop from  $p_0$  to p.

C: speed of the gas rushing out (0.32 m/sec at 20°C)



## II. Pathological-Physiological Study of Explosive Decompression

### A. The Physiological Effect of Gas Expansion

The physiological effect of explosive decompression depends on the degree and the speed of decompression. If the decompression is not significant, the physiological effect is very similar to that of the caisson disease. However, in most cases, explosive decompression happens rather rapidly and violently. Therefore, it causes a great danger even if not too many bubbles are formed. This danger results from the rapid expansion of cavities in the sides, which cause edema of the heart, lung, and stomach. The relationship between the altitude and expansion strength and expansion degree of the internal gas is graphed in Figure 3-20.

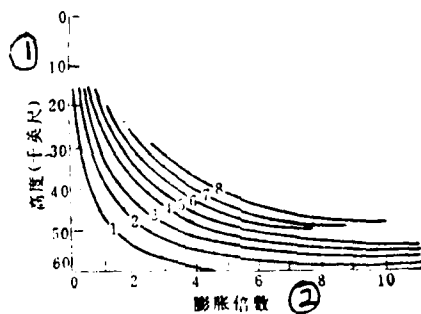


Figure 3-20 The theoretical expansion of internal gas if the pressure difference between inside and outside the cabin is 1-31b/in<sup>2</sup>

Key: 1 - altitude (1000 ft.)  
2 - the degree of expansion

If the atmospheric pressure drops to that of the boiling point of the body fluid (20 km), it will be even more dangerous, because the detrimental effect of boiling will be added to that of the gas expansion. This section will discuss the physiological effect of gas expansion. The problem of boiling of the body fluid will be discussed in the later text.

### 1. Respiratory system:

Under normal conditions, the expanded gas in the lung can be expelled from the tracheae. In the case of explosive decompression, instant decompression will cause the cessation of respiration due to the nerve reflex, which will cause the expansion of gases in the lung, and further result in mediastinal emphysema or gas obstruction. The rapid expansion of the gas in the lung can cause tears in the lung tissue and pulmonary hemorrhage. Exhalation during explosive decompression does more harm than inhalation. Usually, the pulmonary tissue will be damaged if the pressure inside the lung exceeds 100 mm Hg.

### 2. Gas expansion in the abdomen and the digestive system.

Patients show enlarged abdomens and suffer serious pain and discomfort in the abdomen.

### 3. Gas expansion in the middle ear and other sinus cavities.

This gas expansion will lead to the buzzing and pain in the ears, broken drum membrane, swelling pain in the nasal sinus cavity.

### 4. Response of the coronary circulation.

Gas expansion in the lung and the body cavity induces the vagus reflex which results in decreased heart beat, expansion of the peripheral vessels, and temporary drop of the blood pressure. Patients with a history of latent coronary disease will be affected even more seriously. If the explosive decompression is very strong, patients may suffer impaired cardiac function, shock, collapse, and even death. Vasotomized or anesthetized animals will show less serious symptoms in the respiratory and circulatory systems during explosive decompression.

#### c. Central nervous system.

Explosive decompression will induce respiratory and circulatory impairment which causes  $O_2$  shortage at the central nervous system, and a series of serious central nerve symptoms until the patients lose consciousness or die. If explosive decompression is not very serious and pressurization and pure oxygen are provided immediately following the decompression, some of the severe central nerve symptoms can be avoided or relieved. However, the function of the central nervous system, even at the stabilized period, will still be affected.

#### d. Clinical symptoms.

A series of clinical symptoms can be observed among the victims who have been rescued from explosive decompression: purplish skin; chilly feeling; pain under the sternum and in the upper abdomen; irregular breathing; panting; impaired circulation; muscle cramps; muscle pain; dizziness; slow reaction; cessation of breathing; loss of consciousness; even death. If the pressure can be raised to normal right after the loss of consciousness, patients may be able to regain consciousness after 1-15 minutes, but will still show symptoms such as paleness, chilling, headache, nausea, blurred vision, limb numbness, weaker physical strength. These symptoms will last for several hours to several days. The symptoms under different conditions of explosive decompression are shown in Table 3-13.

TABLE 3-13 The relationship of explosive decompression symptoms and speed and duration of decompression

Altitude (m)	Ascending Rate (rate of decompression) (m/sec)	Duration of Decompression	Symptoms
0~0.9	0.5~3600	2.6~6	Symptoms of $O_2$ shortage and swelling of abdomen
2.4~12	3200	3	Incidence of anoxia and intelligence impairment after 5 seconds of exposure
2.4~12	3810	2.5	Tolerable limits when respiratory tract is in good condition
12~15	60 $\pi$	0.005	Due to short duration, symptoms can be avoided if pressure can be raised to normal instantly.
4~20	5250	0.2	Same as above.

Shaking can aggravate the symptoms of explosive decompression. However, the combined effect of explosive decompression and radiation does not increase mortality.

Another problem of explosive decompression deserves some concern: when large cracks appear on the surface of the space ship window, a strong flow of air will rush out from this crack to make it even bigger. Sometimes, passengers and crew members who sit close to the leakage without fastening their seat belts may be sucked out of the cabin or be cut by the broken edges of the leakage. In experiments it has been shown that: A woman model, weighing 41 kg, holding a baby model of 4.9 kg, sits in a window seat (area of the window:  $1554 \text{ cm}^2$ , volume of the cabin:  $6.9^3$ ). The pressure difference (inside and outside the cabin) is  $0.156 \text{ kg/cm}^2$ .

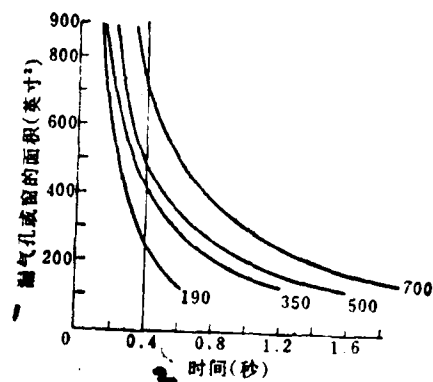


Figure 3-21. Human Limits in the Event of Sudden Cabin Decompression  
 1 - pressure difference ( $\text{Kg/m}^2$ )  
 2 - time (sec.)

When the window is broken, the models are sucked out of the window in 1.85 seconds. The limits most humans can tolerate if leakage occurs is shown in Figure 3-21.

It has been suggested that no windows (or at least as few as possible) should be included in the design of planes which fly only at high altitudes. This proves to be impractical. The only practical way is to educate the passengers to fasten their seat belts to avoid the serious results of broken windows.

### B. Boiling of the body fluids

In daily conversation, boiling means a phenomenon of which the water is cooled to its boiling point. Under 1 atm, the boiling point of water is  $100^{\circ}\text{C}$ , but it can vary with the density of atmospheric pressure: The lower the atmospheric pressure, the lower the boiling point. In other words, the higher the altitude, the lower the boiling point. Table 3-14 lists the relationship between altitude, atmospheric pressure and the boiling point of water. It is indicated in the Table that when individuals are at lower elevation (atmospheric pressure: 760 mm Hg), the water will boil at body temperature (around  $37^{\circ}\text{C}$ ). From the table, it can be seen that, in view, all the water inside the body will boil at 10 km, which is called body fluid boiling. However, since certain enzymes exist inside the body tissue, the actual boiling point altitude of the body fluids is higher than 10 km. Without any protective measures, body fluid boiling is inevitable at 10 km. When explosive decompression occurs above 20 km elevation, the boiling of body fluid becomes life-threatening.

TABLE 3-14 Relationship between altitude, atmospheric pressure and boiling point

(next page)

Altitude (1000 m)	Atmospheric pressure (mm Hg)	Boiling point of water (°C)
0	760	100
1	674	97
2	596	93
3	525	90
4	462	87
5	405	83
6	353	80
7	307	77
8	267	73
9	230	70
10	198	66
11	169	63
12	144	60
13	123	56
14	103	53
15	90	50
16	77	46
17	65	43
18	56	40
19●	48●	37
20	41	35
25	19	22
30	9	10

- The altitude at which the body fluid will boil.

The body fluid boiling can lead to mortality in a very short period. The cause of death is mainly due to the outflow of the oxygen from the tissue, which results in serious  $O_2$  shortage in various tissues. If pressurization and  $O_2$  are supplied immediately, the situation may be improved. However, this kind of incident usually happens rather suddenly and it is always better to prevent it.

Body fluid boiling will produce a large quantity of steam inside the thoracic cavity and further affect breathing seriously. It will also induce bubble formation in the blood and cause circulatory problems. However, these symptoms are not the causes of death; acute anoxia, an acute and drastic symptom, is the killer.

### III. Endurance of Explosive Decompression

The endurance of explosive decompression varies greatly depending on which criterion is used. The most commonly used criteria are:

(1) Effective consciousness time, namely, the period from the beginning of decompression to the loss of working ability.

(2) Physiological tolerable margin, namely, from the beginning of explosive decompression to the margin of physiological injury.

(1) Effective consciousness time:

The so called "effective consciousness" means the ability to sense and identify objects and react according to one's will. Only the effective consciousness can direct individuals to deal with and survive these problems. The effective consciousness during an altitude increase from 1.5 km to 7.5-12 km is shown in Figure 3-22. The effective consciousness time for explosive decompression is shown in Table 3-15. It is indicated in the table that at 19.5 km, at which the body fluid is close to boiling, the effective consciousness time is the same for both explosive decompression and hypobarometric anoxia. This implies that one acute result of body fluid boiling is anoxia which is the main factor that causes mortality.

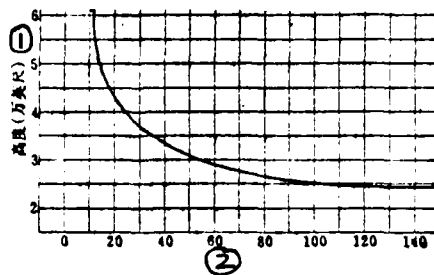


Figure 3-22 Effective consciousness time explosive decompression (the simulated altitude in the closed chamber is suddenly raised from 15 km to 7.5-12 km in 10 seconds)

Key: 1 - altitude (10,000 ft.)  
2 - Time (sec)

TABLE 3-15 Effective consciousness time during explosive decompression

Altitude (km)	Sudden interruption of O <sub>2</sub> supply		Explosive decompression	
	rest	mild exercise	rest	jumping
6.6	10	5	—	—
7.5	3	2	2	1
8.4	1.5	1	1	30
9.0	1.25	45	45	20
10.5	45	30	30	15
12.0	30	18	23	15
19.5	12	12	12	12



(10) Physiological tolerable limit:

One case has been reported: In an accident, one victim was exposed to a drastic decompression situation (from a pressure equivalent to 10.5 km to that of 30 km altitude). He stayed above 19 km (altitude for body fluid boiling) for about 9 seconds, and lost consciousness immediately. Emergency measures were soon taken, and the surrounding pressure was instantly raised to that of 19 km. The victim regained his consciousness in a few seconds and did not show serious aftereffects. However, this case considered to be a border case that man can take physiologically.

IV. Prevention of Explosive Decompression

The preventive measures of decompression basically can all be applied to the case of explosive decompression. However, the following measures seem to be more important for explosive decompression.

(1) The closed-cabin and pressurized suit should be warranted against explosive decompression. This is the most fundamental and important prevention. However, the attacks by enemy planes during combat or the collision with meteors during space travelling are inevitable, therefore, other preventive measures should also be taken.

(2) Wearing the closed pressurized suit: As the atmospheric pressure drops drastically, the pressurized suit can keep the pressure surrounding the skin surface and the pressure of the inhaled air in a tolerable range. The protection of thorax by heavy rubber also has certain effect.

(3) Sufficient  $O_2$ -intake denitrogenization:  $O_2$ -intake denitrogenization before decompression and a sufficient supply of  $O_2$  during decompression have certain preventive effects on explosive decompression.

(4) To minimize the pressure difference inside and outside the cabin. Within the tolerable range, the pressure difference should be minimized. It has been suggested that the pressure difference should be equivalent to the pressure at 8.1 km elevation.

(5) Use gates to separate the cabin into several smaller units and equip the cabin with emergency air-supply devices. When the leakage occurs, the passengers can either be moved to the good units or be supplied with  $O_2$  immediately.

(6) Select adequate gas (which may leak slower) for replacing the regular air (such as  $N_2-O_2$  mixture) inside the cabin.

(7) Develop adaptation and training in a  $O_2$  deficient environment.

## Chapter 14 OXYGEN TOXICATION

### I. Introduction

It has been indicated in the previous chapter that oxygen has to be supplied at an altitude above 3-5km, pure oxygen has to be used above 10-12km, and compressed oxygen has to be provided above 15-18km. Above 19km, an individual has to stay in a closed-pressurized cabin to guarantee safety because the atmospheric pressure is too low and it is close to the altitude of body fluid boiling.

How to supply the  $O_2$ ? There are 2 common ways:

- (1) Use of compressed  $O_2$  or liquid  $O_2$ .
- (2) Reproduction of  $O_2$ : using chemical methods to absorb  $CO_2$  and produce  $O_2$ .

The  $O_2$  pressure and percentage required at various altitudes are shown in Table 3-16 and 3-17. No matter which method is used,  $O_2$  toxication will be induced if the  $O_2$  partial pressure is over 176 mm Hg and the duration is too long. If the  $O_2$  partial pressure is kept under this level, toxication usually will not happen. Unfortunately, under some special cases, the partial pressure has to be raised above 176 mm Hg. For example, when an airplane has to fly at high altitudes at a high speed, a high  $O_2$  partial pressure has to be maintained inside the cabin to prevent the danger of decompression caused by leakage. While flying above 15km elevation, pure oxygen with a pressure of 429 mm Hg (equivalent to the pressure at 4500m elevation) is usually used inside the cabin. Keeping 1/2 atm of pure oxygen in the cabin has also been taken into consideration in the design of space ships to cut down the weight. If the atmospheric pressure

inside the ship exceeds 360 mm Hg, the weight of the space ship will increase almost linearly with atmospheric pressure. If the internal pressure (pressure inside the cabin) is 1 atm, the thickness of the surface has to be 1.5 times that for 360 mm Hg internal pressure. Based on the previous discussions, the internal pressure has to be maintained to meet the body requirements of  $O_2$ , but not high enough to cause  $O_2$  toxication. At the same time, the extra  $O_2$  storage equipment and weight of the shell can be cut down. Nowadays, pure oxygen of 258-360 mm Hg, or slightly higher than 176 mm Hg, is generally used inside space ships.

TABLE 3-16 The requirements for  $O_2$  supply at various altitudes (The  $O_2$  concentration (%) required in the atmosphere to keep the  $O_2$  partial pressure the same as at sea level and 1500m altitude).

Altitude (1000m)	The $O_2$ concentration (%) in the atmosphere to keep the $O_2$ partial pressure the same as that at sea level	The $O_2$ concentration (%) required in the atmos- phere to keep the $O_2$ partial pressure the same as at sea level
0	21.0	17
1.5	25.5	21
3.0	31.3	26
3.4	38.8	32
6.0	48.8	40
7.5	62.4	51
9.0	81.2	67
10.5	108.7	89

TABLE 3-17 The  $N_2$  and  $O_2$  percentage required to keep the partial pressure the same as at various elevations

Altitude (1000m)	Atmospheric pressure (mm Hg)	$O_2$ conc. (%) in the inhaled wet air	$N_2$ conc. (%) in the inhaled wet air	Max. $O_2$ partial pressure in dry air (mm Hg)
Sea level	760	21	79	760
1	574	24	76	674
2	596	27	73	596
3	526	31	69	526
4	462	36	64	462
5	406	42	58	406
6	354	49	51	354
7	308	57	43	308
8	207	68	32	267
9	230	82	18	230
10	198	99	1	198

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The  $O_2$  partial pressure is usually kept under 1 atm in airplanes and space ships. However, prolonged inhalation of this air still can cause  $O_2$  toxication. Therefore, it is still necessary to consider  $O_2$  toxication occurring for 1 atm  $O_2$  partial pressure.  $O_2$  toxication occurring above 1 atm will not be discussed here since it rarely happens in air or space travel.

## II. Physiological Effects and Clinical Symptoms of $O_2$ Toxication

### A. Physiological effects

The physiological effect of  $O_2$  toxication appears mainly in the respiratory system, cardiovascular system and blood composition. When  $O_2$  partial pressure exceeds 1 atm, its effect on the central nervous system becomes very significant. As the oxygen pressure is under 1 atm, it usually does not have a serious effect on the central nervous system.

#### 1. Respiratory system

##### (1) Lung collapse and injury

One common symptom of inhaling pure  $O_2$  is lung collapse. It is caused by the complete absorption of pure oxygen, collected in the pulmonary alveoli, by the lung tissue. The gases are not easily absorbed; therefore, the inhalation of the mixed gases will always leave some gases in the lung and keep it expanded. In this case, the incidence of lung collapse is rare. The collapse will cause the neighboring alveoli to stick together and collapse. As the collapse area in the lung enlarges, the difficulty in breathing will be increased greatly. If the collapsed pulmonary alveolus is re-expanded, it will stimulate the elongation sensor in the lung, and cause

coughing through the nerve reflex. Pure oxygen can also irritate the trachae and bronchial mucosa; therefore, serious  $O_2$  toxication will always result in bronchitis, collapse of the bronchial tree, and pulmonary dropsy. The acute symptoms are dropsy and thickening of the pulmonary artery. Fluid collects around the blood vessels and inside the alveolus, which will result in pulmonary dropsy. Occasionally, the thrombus can be found in the pulmonary blood vessels and the broken alveolus capillary membranes are also observed. Chronic and late-stage symptoms are proliferation of alveolus fiber which causes irreversible damage to the function of the pulmonary alveolus.

(2) The accumulation of  $CO_2$  in the tissue

The high  $O_2$  content in the respiratory gas will increase the dissolving of  $O_2$  in the blood, which exceeds the  $O_2$  requirement of the tissues. Therefore, the concentration of the oxygenated hemoglobin in the circulation will increase correspondingly and, on the other hand, that of the deoxygenated hemoglobin will decrease. Since the transport of  $CO_2$  is seriously cut down,  $CO_2$  will accumulate in the tissues. The drop of  $CO_2$  partial pressure in the arterial blood will cause the blood vessels to constrict, and pulse rate, cardiac output to decrease, and also a corresponding decrease of the blood flow in the tissues. This will further enhance the accumulation of  $CO_2$  in tissues, and affect the release and transport of idle gases in the tissues.

(3) The irregular breathing caused by diaphragm cramps

The symptoms, such as the pain under the sternum, cough, pressure in chest, chest pain, irritated respiratory tract and lung, and difficulty in breathing, usually occur after the inhalation of pure oxygen. Although some individuals show

mild symptoms (cough, difficulty in breathing, chest pain due to respiratory tract and lung irritation) after 6-7 hours of exposure to pure oxygen (1 atm), the majority of the population will start to show symptoms only after 14 hours of exposure and suffer more severely after 60 hours.

## 2. The cardiovascular system

Under a high  $O_2$  partial pressure, the heart beat and pulse rate will drop, but no significant change can be observed in the blood pressure and cardiac output. If the toxication is not serious, its effect on the cardiovascular system usually is not very strong.

## 3. Blood

The effect of  $O_2$  toxication in the blood appears as decrease in the erythrocyte numbers, hemoglobin concentration, and erythrocyte/leukocyte ratio, and the increase in leukocyte numbers and reticular cells. Study results are summarized in Table 3-18. These symptoms will occur under the following conditions: (1) exposure to 1 atm pure oxygen for several hours (2) exposure to pure oxygen less than 380 mm Hg for more than 14 days. The erythrocyte/leukocyte ratio will still drop slightly (3-6%) after 17 days of exposure to an environment where the  $O_2$  partial pressure is 176 mm Hg. These changes in the blood are reversible.



TABLE 3-18 Changes of blood composition caused by O<sub>2</sub> toxication

Total atmos- pheric pres- sure (mm Hg)	O <sub>2</sub> par- tial pres- sure (mm Hg)	no. of people tested	duration of expos- ure	no. of erythr- ocytes	hemo- glo- bin	eryth- rocyte leuko- cyte ratio	no. of leuko- cyte	no. of reticu- lar cell	Other changes
760	760	3	4 hrs.			+			
760	760	-	-	begin- ning + then recover					
760	760	1	several hours						
760	760	normal, patient	4-14 days						inhibition of the combining of iron molecules with hemoglobin
760	508	patient	8-20 days	+					life span of erythrocytes is very short and the reticular cells are numer- ous for these patients
380	380	7	14 days		+		+		
258	258	2	14 days	no change					

Total atmos- pheric pres- sure (mm Hg)	O <sub>2</sub> par- tial pres- sure (mm Hg)	no. of people tested	duration of expos- ure	no. of erythr- ocytes	hemo- glo- bin	eryth- rocyte leuko- cyte ratio	no. of leuko- cyte	no. of reticu- lar cell	Other changes
258	258	6 (pilot)	14 days		+	+	+	+	no significant change for platelet. All the criteria are back to normal value after 3 months.
258	253	(pilot)	20 days	no change	no change	no change	no change	no change	
258	253	7	14 days	+			+		the diameter of erythrocytes changes. The erythrocytes appear to be flat and wider
258	258	7	21 days			+(90%)			the concentration of Latic Dehydro- genase drops 17.2%
258	254	4	>14 days			+(90%)			The O <sub>2</sub> partial pressure in the arteries is 169.7 mm Hg.
700	233	4	>14 days			+(7%)			The O <sub>2</sub> partial pressure in the arteries is 177.7 mm Hg.

TABLE 3-19 (Continued)

Total atmos- pheric pres- sure (mm Hg)	O <sub>2</sub> par- tial pres- sure (mm Hg)	no. of people tested	duration of expos- ure	no. of erythr- ocytes	hemo- glo- bin	eryth- rocyte leuko- cyte ratio	no. of leuko- cyte	no. of reticul- lar cell	Other changes
196	196	7	14 days		+		+	+	the no. of lymphocytes increases. The diameter of eryth- rocyte changes, and it appears to be flat and wide.
181	181	1	-	no change	no change	no change	no change	no change	
176	176	2	17 days			+			blood volume decreases.
360	150	2	30 days	+		+			blood volume decreases

Note: + indicates "increase".

+ indicates "decrease".

#### 4. The urine composition

The excretion of adrenaline and noradrenaline in the urine is inversely proportional to the  $O_2$  partial pressure after 4 hours of exposure to 760, 456, 160, 114 mm Hg of  $O_2$  partial pressure (total atmospheric pressure: 1 atm). The noradrenaline/adrenaline ratio drops with the decrease in  $O_2$  concentration (from 2:1 to 6:1). Under 1 atm of pure oxygen, the phosphorus concentration in the urine may appear to be below normal.

#### 5. Vision and hearing

After inhalation of 1 atm pure oxygen for 5-30 minutes, the diameter of the retinal artery decreases 17%, and that of retinal vein decreases 20%. These changes are reversible. Under the same circumstance, the hearing ability will degenerate after 20 min., but it can be recovered after a period of time.

#### B. The Clinical Symptoms and Disease Mechanism of $O_2$ Toxication

The inhalation of the air, in which  $O_2$  partial pressure is slightly higher than 176 mm Hg, for a long period of time will cause some abnormal responses and clinical symptoms which mainly appear in the respiratory system, cardiovascular system and blood composition. The clinical symptoms indicate the direct correlation between the  $O_2$  partial pressure and the duration of exposure.

If the  $O_2$  partial pressure is maintained under 176 mm Hg (not including the lack of  $O_2$ ), the symptoms usually will not

occur. Exposure to  $O_2$  partial pressure of 176 mm Hg for more than 17 days will cause some malignant effects, mainly discomfort under the sternum. Exposure to the same environment for more than 1 month will cause more symptoms and the degeneration of the cardiovascular function. Exposure to the  $O_2$  partial pressure of 180-300 mm Hg for more than 14 days, more symptoms occur, such as irritated nasal and laryngeal mucosa, irritated respiratory tract and lung, slight decrease in the vital capacity, decreased body weight, decreased working efficiency, increase of reticular cells in blood, decrease in the number of erythrocytes, and degenerated dark adaptation, etc.

After exposure to the  $O_2$  partial pressure of 320 mm Hg for 1 day, the pulse rate will drop significantly. After exposure to 380 mm Hg ( $O_2$  partial pressure) for 3 hours, half of the population will suffer chest pain, cough, and incomplete lung expansion, which are the indications of the beginning of lung collapse. Individuals exposed to  $O_2$  partial pressure under 760 mm Hg for 4 days will usually suffer symptoms in the respiratory and circulatory systems as described above, but, some will occasionally suffer abnormal sensation, decreased efficiency, fatigue and vomiting, which indicates the toxication of central nervous system.

The disease mechanism of  $O_2$  toxication still remains a subject of controversy. There are two different theories: (1) The functional change of respiratory and circulatory system, esp. lung collapse and the increase of oxygenated hemoglobin which decreases the transport of  $CO_2$ . (2) The anesthetic effect of high  $O_2$  partial pressure on the central nervous system.

Since most of the  $O_2$  toxication cases which occurred under 1 atm do not show any symptoms of toxication of the central nervous system, it seems the exploration of the disease mechanism should be concentrated on the respiratory and circulatory systems.

### III. Safety and Prevention

#### A. Prevention of $O_2$ toxication

The most effective way to prevent  $O_2$  toxication is to control the  $O_2$  concentration and  $O_2$  partial pressure of the surrounding atmosphere. The  $O_2$  partial pressure can be controlled within a tolerable range by adding idle gases into the inhaled air. If the  $O_2$  partial pressure cannot be maintained within this range for some reasons, the duration of exposure has to be limited. If necessary, the  $O_2$  and air can be supplied in turn to avoid the danger of  $O_2$  toxication.

If the toxication has already occurred, the high-concentration  $O_2$  has to be replaced by other breathing air. Clinical treatments are necessary in the case of chronic toxication.

Since pure oxygen is commonly used in the clinical treatment, the prevention and treatment of  $O_2$  toxication has been well developed.

#### B. Safety Problems

Oxygen can help combustion. The high concentration of  $O_2$  or pure oxygen can easily include fire in a high  $O_2$  pressure environment. Some studies indicate that the chance the textile catching fire under an  $O_2$  pressure of 258 mm Hg (pure

oxygen) is 3.5 times that for an atmospheric pressure of 560 mm Hg. The flammability of the textiles and the increase of temperature caused by fire, in addition to the unique effect of the oxygen, will cause the fire to spread even faster. This combining effect will be more significant if the  $O_2$  (pure) pressure exceeds 258 mm Hg. On January 27, 1967, an accident caused the death of three crew members of Apollo-13 even before it took off. A spark in the electronic system set the space ship on fire which was filled with pure oxygen. In only 12 seconds, all the crew lost their lives. The plastic equipment inside the cabin and the astronauts' suits were all burned out. Not only sparks, but also collisions with meteors (which can cause high heat and strong impact waves as the meteor penetrates the surface) can set such a space ship (with high  $O_2$  concentration inside the cabin) on fire. It has been demonstrated that: A small aluminum bullet travelling at the speed of 6-7 km/sec hits a model space ship. If the cabin is filled with pure oxygen, the intensity of the spark can reach 3-20 million candle-powers. A large quantity of  $Al_2O_3$  is deposited on the surface and experimental animals (rats) are instantaneously killed in the cabin. The skin and lung of the deceased animals are seriously burned. On the contrary, if the cabin is filled with regular air, the rats can survive with different degrees of burn injury. The relationship between the fire hazard and the gas content inside the cabin is demonstrated in Table 3-19 and 3-20.

TABLE 3-19 The fire hazard index no. of various space ships  
with different air composition inside the cabin.

Air composition	Total atmospheric pressure (1000kg/m <sup>2</sup> )	O <sub>2</sub> partial pressure (1000kg/m <sup>2</sup> )	Fire hazard index no.
Pure O <sub>2</sub>	3.6	3.6	8
Pure O <sub>2</sub>	12	12	7
60% N <sub>2</sub> , 40% O <sub>2</sub>	12	7	11
Regular air	11	2	33
Regular air	43	9	17
Regular air	216	45	7
60% O <sub>2</sub> , 40% N <sub>2</sub>	12	7	10
15% O <sub>2</sub> , 85% N <sub>2</sub>	12	2	44
28% O <sub>2</sub> , 36% N <sub>2</sub> , 36% He	40	11	12
2% O <sub>2</sub> , 97% He	216	6.5	29
2% O <sub>2</sub> , 98% He	216	4	55



TABLE 3-20 The relationship of the fire hazard index no. and the seriousness of the fire

Fire hazard index no.	Seriousness of the fire	The specification of material for preventing the fire
>50	flame will not spread around	no special specification
40 50	marginal	selection of less-flamable material
30 40	intermediate-similar to the fire in ordinary atmosphere	use the material which can either stop or delay the fire
20 30	increased danger	same as above, even this material should be used as little as possible
10 20	extremely dangerous	use non-flamable materials
<10		

In order to avoid fire hazards, not only the prevention and fire fighting measures, but also the control of  $O_2$  concentration in the cabin should be considered. The  $O_2$  partial pressure inside the cabin should be kept under  $2500\text{kg/m}^2$ , if not possible, at least under  $3600\text{kg/m}^2$ . Pure oxygen should be prohibited inside the space ship. Should it (pure oxygen) be used for technical or other reasons, the following preventive measures should be taken:

(1) Before the take-off, the cabin can be supplied with 1 atm (or less) air, or a gaseous mixture of 60%  $O_2$  and 40%  $N_2$ . After the take-off, the internal pressure can be dropped to  $7000\text{kg/m}^2$  (including inside the astronaut's suit), and the air composition can be changed to a mixture of 33%  $O_2$  and 67%  $N_2$ .

Not until 4 hours later can the pure oxygen of  $3600\text{kg/m}^2$  be used. After ten hours or 1 day, the pressure of pure oxygen inside the cabin is dropped to the minimum tolerable limit,  $2500\text{ kg/m}^2$ .

(2) Replace the flammable materials with less-flammable materials.

(3) Improve the insulation of circuits.

(4) Install emergency exits and fire fighting equipment. An escape device which can eject the crew out of the cabin in 3 seconds has been suggested.

(5) Use non-flammable coolant, replace all the materials which will disintegrate under  $200\text{-}400^\circ\text{C}$  by those which can stand  $300^\circ\text{C}$ .

(6) Replace the nylon in the astronaut's suit by 8-type fiber glass. Use less-flammable material for wires, helmets, shoe soles, cushions, etc.

(7) Cut down the tube connections as much as possible. Flammable materials, such as rubber, should all be replaced in the ventilation system.

(8) Use less-flammable materials for notebooks and belts, and keep them in the fire resistant boxes.

(9) Conductor should be changed to nickel thread, for which the melting point can reach  $870^\circ\text{C}$ . Experiments can be conducted under the pressure of  $4600\text{kg/m}^2$  in this case.

(10) Fire-resistant material should be used for the cabin.

(11) Fire extinguishers should be placed near the crew or inside the cabin. Fire fighting and emergency training should be given to the crews.

(12) One effective way of fire-fighting: as the fire occurs, open a hole on the cabin surface and let the air rush out in a few seconds to make a vacuum inside the cabin. The space ship using pure oxygen should have this fire-fighting device.

## PART IV Thermo-environmental Medicine

### Introduction

Body temperature remains at a constant value, but not that of the environment. Body temperature is regulated by a series of physiological processes that can keep it constant and prevent its fluctuating with surrounding temperatures. Human beings can also use their wisdom to change surrounding temperatures to make more areas suitable for habitation.

In outer space the surrounding temperature is not quite the same as that on the earth's surface, e.g., the temperature at high altitudes is much lower. Space ships or airplanes are also exposed to relatively high temperatures as they return from outer space to the earth's surface; during take-off and return to earth, friction between the air and a space ship produces high intensity of heat, which will increase the cabin temperature considerably despite the space ship's insulation and heat-dissipating devices. Fluctuation of environmental temperatures is still an unsolved problem in aeronautics and space travel.

Environmental temperature requirements will be discussed in this part, namely optimal and tolerable temperatures, the damage done to the human body by cold and heat, and its prevention.

### Chapter 15 The Relationship of Body Temperature to Environmental Temperature

#### I Body Temperature and Environmental Temperature

The internal temperature of the human body is commonly referred to as "body temperature." Body temperature, usually taken orally or rectally, is very constant. Normal body temperature is around  $37^{\circ}\text{C}$ , with one degree of variation. If it is above  $38^{\circ}\text{C}$ , individuals will feel fever and discomfort; on

the other hand, individuals will feel chilly and uncomfortable when it is under  $36^{\circ}\text{C}$ . This indicates that the human being can adjust to only a small range of body temperature. Fortunately, the regulatory mechanism in the human body can maintain body temperature in a normal range if the environmental temperature does not change drastically.

Body temperature is very stable, but not so that of the environment humans live in. The temperature at the earth's surface ranges from  $+50^{\circ}\text{C}$  to  $-7.5^{\circ}\text{C}$ . The average annual temperature in most areas is about  $+20^{\circ}\text{C}$ . The average annual temperature of China is from  $4$  to  $23^{\circ}\text{C}$ , with extremes of  $\pm 45^{\circ}\text{C}$ . The temperature changes greatly as the elevation increases, and temperatures of different atmospheric layers are also different. The changes of temperature in different seasons at various elevations and atmospheric layers are shown in Figure 4-1 and Figure 4-2. Individuals will experience different temperature environments during space and air travel. The temperature change will be even more drastic if the destination is another planet. The temperature change on the moon's surface can be  $100^{\circ}\text{C}$  from day to night. For this reason, the study of temperature changes in the environment can be a very extensive subject in aeromedicine.

## II The Temperature of Airplanes and Space Ships

### A. The Temperature of Airplanes

As airplanes travel at different altitudes, they encounter different temperature environments. From the point of view of kinetics, the speed of the airplane will cause friction between itself and the surrounding atmosphere. For example, a supersonic plane will produce large amounts of heat on its surface while traveling. This heat is the result of energy consumed by the airplane in overcoming the drag force of the surrounding atmosphere.

It can be calculated approximately as follows:

$$\Delta T(^{\circ}\text{C}) \approx \left(\frac{V}{62}\right)^2 = \left(\frac{V_1}{87}\right)^2$$

$\Delta T$  - Temperature increase on the surface of the plane ( $^{\circ}\text{C}$ ).

$V$  - Flight speed (not considering the friction): Km/hr.

$V_1$  - Flight speed (not considering the friction): mile/hr.

Part of the heat produced by the friction will be dissipated into the surrounding atmosphere; therefore, the real surface temperature of the plane will be slightly lower than that calculated as heat balance is reached. The above equation only shows the relationship between the surface temperature and flight speed and not between the surface temperature and altitude. In fact, the temperature increase on the plane's surface usually exceeds the surrounding temperature, which is closely related to altitude. At different altitudes, the heat dissipated from the plane into the surrounding atmosphere is also different. Therefore, the surface temperature will vary with altitude even though flight speed is the same. Besides, the air flow of the surrounding atmosphere has a certain effect on the surface temperature. The surface temperature will be lower in a stable atmosphere than in turbulent air flow. The insulation on the ship's surface will make the cabin temperature lower than the surface temperature.

As for the heat produced by friction, compressing the surrounding air there will also contribute to heat production, which will raise the temperature to  $312^{\circ}\text{C}$ . Considering all these heat-producing factors, airplanes must be equipped with necessary cooling devices to provide reasonable working conditions. On the other hand, when an airplane travels at supersonic speed, the heat dissipation may be very large due to the low surrounding

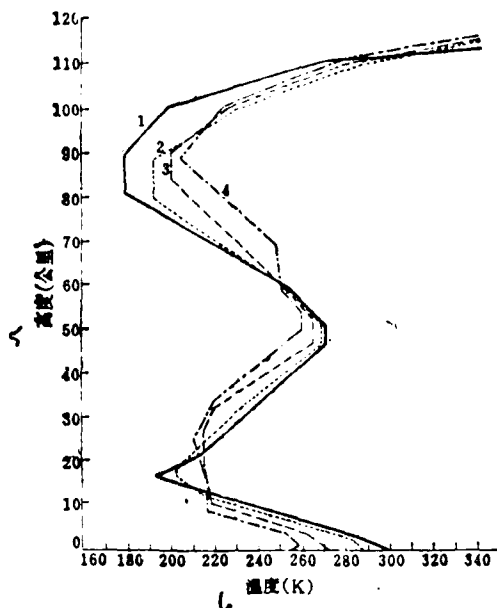


Figure 4-1. Temperature at different altitudes (A): 1) average annual temperature,  $15^{\circ}\text{N}$ ; 2, 3, 4) January average temperature at  $30^{\circ}\text{N}$ ,  $45^{\circ}\text{N}$ ,  $60^{\circ}\text{N}$ ; 5) altitudes, Km; 6) temperature, K.

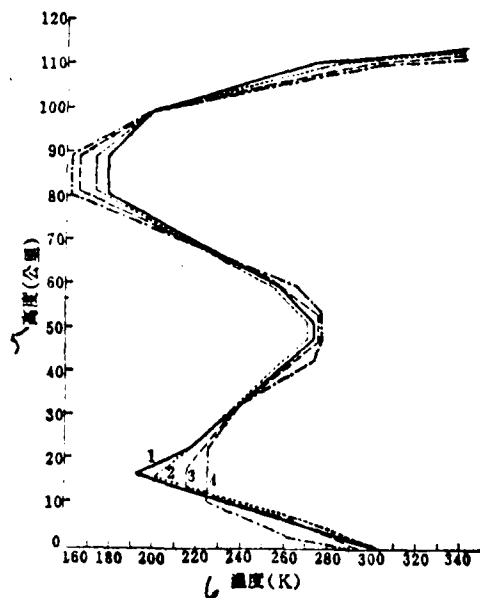


Figure 4-2. Temperature at different altitudes (B): 1) average annual temperature,  $15^{\circ}\text{N}$ ; 2, 3, 4) average temperature of July at  $30^{\circ}\text{N}$ ,  $40^{\circ}\text{N}$  and  $60^{\circ}\text{N}$ ; 5) elevation, Km; 6) temperature, K.

TABLE 4-1 REQUIREMENTS OF HEATING AND COOLING FOR KEEPING CABIN TEMPERATURE AT 18°C (AT VARIOUS ALTITUDES)  
(Internal pressure kept at that of 2400 m elevation)

ALTITUDE (1000 m)	CORRESPONDING ALTITUDE OF INTERNAL PRESSURE (1000 m)	SURROUNDING TEMPERATURE (°C)	HEAT LOSS OF THE CABIN (BTU/hr)	TEMPERATURE REQUIREMENT OF AIR SUPPLY	TEMPERATURE PRODUCED BY COMPRESSING THE AIR (°C)	AMOUNT OF HEATING REQUIRED (BTU/hr)	AMOUNT OF COOLING REQUIRED (BTU/hr)
2.4	2.4	-0.55	2800	54	-0.55	3200	
5.7	2.4	-18	6700	47	18	3000	
8.9	2.4	-41	8200	60	30	3700	
12.1	2.4	-55	10300	64	62	2000	
12	2.4	-68	14200	63	104		2700
18.5	8.9	-65	10000	62	107		11100

NOTE: Assuming the insulation of the surface is 0.55 BTU/hr, surface area is 18 m<sup>2</sup> and the lowest inner-surface temperature is 18°C, the temperature increased caused by the friction can be ignored if the flight speed is under 420 Km/hr.



temperature, causing cabin temperature to be lower than desired so that heating may be required. Requirement of heating and cooling in the cabin at various altitudes is shown in Table 4.1.

Other factors such as latitude, geographic factor (above desert or ocean), season and other meteorological conditions will also affect cabin temperature. Without temperature regulation, cabin temperature can reach  $70^{\circ}\text{C}$  while flying above the tropical desert and can drop beneath  $-20^{\circ}\text{C}$  while flying over the North or South Pole.

#### B. Temperature of Space Ships

The heat resources of the satellite-type space ship as it travels in its orbit are: 1) solar radiation from the sun; 2) solar radiation reflected from the earth's surface; 3) heat radiation from the earth; 4) heat radiation from outer space; 5) heat radiation from the power supply of the space ship (including the devices inside the cabin); and 6) heat dissipated from the human body inside the cabin. The absolute temperature of outer space is  $4^{\circ}\text{K}$ , and therefore the heat radiation from it can be ignored. The same is true for heat conduction from outer space to the space ship. In other words, the heat resources of the space ship are mainly from categories 1), 2), 3), 4), and 6).

Above 200 Km, although the atmospheric temperature can be as high as  $800-2000^{\circ}\text{C}$ , the real surface temperature of the space ship is not very high, due to the effect of thin air. The space ship traveling around the earth can receive  $1.94 \text{ cal/min. cm}^2$  of solar radiation on the side that faces the sun. Therefore, the surface temperature on this side can reach several hundred degrees centigrade. But the surface temperature of the side which is in the shadow of the earth can drop to lower than  $-29^{\circ}\text{C}$ . The data in Table 4-2 can be used as reference.

TABLE 4-2 SURFACE TEMPERATURE OF THE SPACE SHIP

SURFACE OF SPACE SHIP	FLAT FORM COMPLETELY INSULATED ON BOTH SIDES (at 192 Km altitude)		
	SIDE FACING SUN	SIDE FACING BRIGHT SIDE OF EARTH	SIDE FACING DARK SIDE OF EARTH
White	51°C	- 13°C	- 29°C
Black	122°C	68°C	- 29°C
Smooth Aluminum Surface	428°C	295°C	- 29°C
SURFACE OF SPACE SHIP	GLOBE (AT 192 Km ELEVATION)		
	DAYTIME	NIGHTTIME	
White	42°C	- 28°C	
Black	63°C	- 68°C	
Nickel	293°C	- 68°C	

On its way back to earth, the space ship will receive 5500 Kcal/Kg of heat as it passes through the atmosphere ~~at an altitude of 160 kcal,~~ at the speed of 6.4 Km/sec. Theoretically, the temperature of the space ship can reach 8000-10000°K under this circumstance if there is no cooling system available. However, the actual surface temperature can never be so high for the following reasons: 1) the returning speed has been reduced greatly; and 2) the nitrogen and oxygen in the atmosphere will be ionized into free ions as the ship surface contacts the atmosphere at high speed. This process of ionization will consume energy and decrease the surface temperature of the ship. In fact, the surface temperature of the space ship can still reach 2000-3000°C. Not only can human beings not withstand so high a temperature, some of the surface materials will be burned out, also. Therefore, the appropriate heat-dissipation measures should be taken. Even then, the surface and cabin temperatures will still be raised to a very high level during the return trip. The temperature increase rate can be as high as 28°C/min, and the surface temperature can be kept at the maximum value of 138-205°C for twelve minutes and then drops. If the cooling system inside the cabin is out of order at this time, the surface temperature can reach as high as 427°C. No danger will be caused if appropriate emergency measures can be taken promptly.

In addition to the solar energy and the heat produced by friction, human beings, themselves, are a heat source. The average heat production of human beings is 125 Kcal/hr or 146 watts. If there are no appropriate heat-dissipation devices, the accumulation of this heat can raise the cabin temperature to a very high level. In any case, the heat-dissipation device is essential to the space ship. For dissipating the heat produced by the human body, the requirements for surface radiation area (assuming the surface area is 4°C) and air flow rate in the cabin are shown in Figure 4-3.

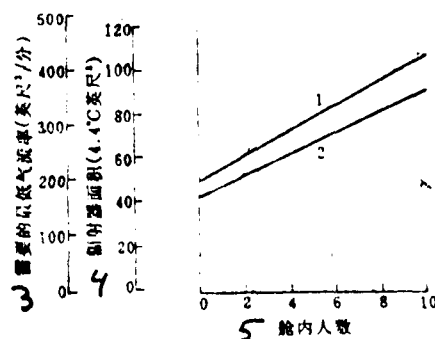


Figure 4-3. The requirement of the cooling system of the space ship: 1) air flow rate; 2) surface area of the radiator, power of cooling system 1250W, power consumed per radiation plate 1/5 of that of space ship; 3) minimum air flow rate, feet<sup>3</sup>/min; 4) surface area of the radiator, 44°C, feet<sup>2</sup>; 5) number of crew.

In order to guarantee a comfortable temperature inside the cabin under differing conditions (i.e. high temperature caused by solar radiation and friction, low temperatures in outer space) good insulation, heat-dissipation, heating and cooling systems are essential. In addition to this, a certain temperature-regulating air flow system should also be installed because the air flow has to be maintained by this regulating system (fan) under the weightless situation.

### III Regulation of Body Temperature

Except for some pathological situations (e.g. fever), the body temperature of the human being is quite constant. Temporary increase (e.g. while exercising) or drop (e.g. while taking a cold shower) of body temperature will soon be recovered from, indicating the existence of the regulatory system in the body. Heat production is mainly a chemical reaction, the oxidation of material. Heat dissipation is a physical process which functions through radiation, convection, conduction, vaporization, respiration, excretion and urination. About three-quarters of the oxidation products transform into heat. An adult will produce 2000 Kcal every day under normal conditions, and any strenuous activity

will add hundreds of thousands of cal per hour to this figure. In order to maintain constant body temperature, our bodies must continue to lose heat. In temperate climates, 75% of body heat loss is through radiation, convection and conduction, 15% through sweating and vaporization, 7% through respiration and 3% through excretion and spitting. The temperature difference between body surface and surrounding environment decides direction of radiation, conduction and convection as heat moves from high temperature areas to low temperature areas. The greater the temperature difference, the faster heat is dissipated. Heat conduction refers to heat loss through direct contact of body surface with solid material, liquid or gas. Convection refers to heat loss through circulation of air or water. For example, layers of warmed air next to the skin are constantly replaced by cooler air as lighter warm air rises. Sweating can be categorized into conscious and unconscious perspiration. In the former, sweat can be seen on the body surface, and its vaporization removes heat from the body surface. The latter refers to the direct vaporization of water through skin surface, including in part that from the sweat glands. Vaporization of 1 gm water will consume 0.58 Kcal heat, including heat loss from warmer areas of the skin. The temperature and water content of inhaled air are very similar to those of the surrounding atmosphere, which are usually lower than those of the body. Exhaled air is saturated with water, and its temperature is the same as the body temperature. Vaporization of  $\text{CO}_2$  absorbs heat, and heat and vapor can also be lost from the mouth through conversation. All of these are indications of heat loss through respiration. In addition to these forms of heat loss, a small portion of heat is also removed through excretion, urination, spitting and tears.

Within a short period of time, heat production and heat losses must be brought into balance in order to maintain body temperature at a constant level. If heat production exceeds heat loss, it implies that some of the heat will be stored in the body, called

"cold debt". When heat is accumulated to a certain level, body temperature will rise. The more heat the body stores, the higher the temperature will be. On the contrary, if heat production is less than heat loss, "heat debt" will be built up in the body. Body temperature will drop when "heat debt" reaches a certain level. Under normal conditions, the heat storage or heat debt is just a temporary process. For example, strenuous exercise will temporarily cause high body temperature when the environmental temperature is very high, and extremely low environmental temperature will cause temporary low body temperature. Once the environmental conditions are back to normal, this temporary change of body temperature will be adjusted, indicating that heat production and loss are always in kinetic balance.

The regulatory mechanism of heat loss can be either physical or physiological. The physiological type can also be classified into two categories: reflex and voluntary. Both will be discussed:

1. Voluntary regulatory mechanism: This refers to the case where individuals take temperature-regulating measures consciously according to their feeling, e.g. changing clothes as the weather changes, avoiding heat sources intentionally.

2. Reflex regulatory mechanism: This refers to the unconscious temperature-regulating reflex. When environmental temperature stimulates the cold or heat receptors in the skin, the excited receptor will send out a nerve impulse which travels through the motor nerve to the effectors, which will respond to the message and cause the reflex. The effectors can be organs or tissues which show different responses. The effectors in muscles can cause the constriction or relaxation of the muscle, and in the blood vessels they can cause them to constrict or dilate. The temperature receptors of the human body are mainly located in

the inner layers of the skin. The temperature receptors can also be found in the thalamus. The temperature receptors in the skin can sense the degree and direction of the temperature difference, but not the absolute environmental temperature. In other words, it can sense the temperature difference between the inner layer and outer layer of the skin and send messages to the central nervous system.

The temperature sensor in the thalamus will sense the temperature change inside the body. Two temperature-sensor centers, one sensitive to cold and the other sensitive to heat, are located in different areas of the thalamus. These two centers are extremely sensitive to the temperature change of their surroundings and the central nervous system. The change of only  $0.01^{\circ}\text{C}$  can stimulate both centers. The cold-sensitive center can sense the temperature change in the lower range ( $33\text{--}36^{\circ}\text{C}$ ), and the heat-sensitive center is sensitive to the change in the higher range ( $37\text{--}39^{\circ}\text{C}$ ). The excited central nervous system can initiate a series of reflexes to regulate the body temperature. These two centers (or receptors) are located very close to the sympathetic nerve center of the thalamus and have abundant nerve fibers connected to them. This sympathetic nerve center in the thalamus is also connected to the sympathetic nerve center of the cerebrum, the medulla and the spine. Therefore, the temperature receptors in the thalamus serve not only as temperature receptors but also as the reflex nerve center. Their function of temperature regulation is closely related to the function of the sympathetic nerve center. A series of the regulatory mechanisms are controlled by the sympathetic nerve center. The response of body temperature regulation can be categorized as follows:

- 1) Arterioles and capillaries (together as blood vessels)

This is an important effector for the temperature difference

in the skin, especially the blood vessels in the skin. Blood vessels of internal organs function oppositely but complementarily to those of the skin. Function of the blood vessels is regulated by the sympathetic nerve, which is controlled by the sympathetic nerve center in the brain. When environmental temperature increases to a certain level, the temperature receptors in the skin can sense the difference between the internal (body) and environmental temperatures and form a heat stimulus, causing the individual to feel hot. A series of reflexes can also be triggered, including dilation of blood vessels in the skin and muscle and constriction of blood vessels of the internal organs, especially the liver, spleen and digestive tract. A large quantity of blood will then flow from the internal organs toward the skin and muscle, bringing warmer blood to the cooler skin surface and increasing heat loss by radiation, conduction and convection. A minor increase in body temperature will stimulate the heat receptor in the anterior thalamus and further enhance regulatory reflexes of the blood vessels. This regulatory mechanism works especially effectively when environmental or skin temperature is lower than internal body temperature. When skin temperature is higher than internal body temperature, this regulatory mechanism of the blood vessels will lose its function, and heat must be lost by vaporization of perspiration on the skin surface.

On the contrary, when environmental and skin temperatures drop to a certain level or the body temperature drops slightly, the cold receptor in the posterior thalamus will be stimulated, and other related reflex centers will also be excited by the cold-message sent in by the skin receptor. At this time, the function of the sympathetic nerve is to cause constriction of blood vessels in the skin and muscle and dilation of blood vessels in internal organs. In this way, heat can be stored, heat dissipation can be reduced, and the feeling of chill can be relieved. When the drop in body temperature is drastic, not only the cut-down of heat loss but also an increased heat production are necessary to main-



tain constant body temperature. The most effective means of heat production is voluntary contraction of the striated muscle. In extremely cold weather, increase of the reflex tension of the striated muscle and shivering of the body are also helpful for heat production.

## 2) Heartbeat rate and respiration

Increase of body temperature will cause an increase of heartbeat rate, which has a high correlation with rectal temperature. The increase in rate of the heartbeat will not exceed that of body temperature until it is over 120 times per minute. Most individuals cannot stand a heartbeat rate of higher than 140 times per minute. Increase of the heartbeat rate is a result of the excited function of the sympathetic nerve and a direct effect of warmer blood in the heart. Increase of the heartbeat will cause an increase in cardiac output per minute and will further improve blood circulation, which is beneficial to heat dissipation. However, when the heartbeat reaches more than 120 times per minute, cardiac output per minute will begin to decrease as the heartbeat increases. Drop of body temperature will decrease the pulse rate, but a drop of more than  $2^{\circ}\text{C}$  is necessary for significant results to be seen.

## 3) Secretion of the sweat glands

Secretion and vaporization of sweat is one of the important mechanisms of heat loss, especially when environmental temperature is higher than body temperature. Sweat glands are controlled by the sympathetic nerve. When the heat receptor of the thalamus is excited, it sends out an impulse to the sweating center, which will then send a message to the sweat glands through the sympathetic nerve, to cause perspiration. The heat loss for sweat production is not significant when environmental temperature is higher than body temperature, but vaporization of the

sweat plays an important role in heat loss. For every gram of water vaporized, 0.85 Kcal of heat will be consumed. In extremely hot and dry weather, a person can sweat 4-5 Kg, namely losing 3320-2900 Kcal through vaporization which is almost the total heat loss. If the weather is humid, the vaporization will not be as efficient as in dry, hot weather. Therefore, even if the body produces the same amount of sweat, the heat loss through vaporization will still not reach 3320-2900 Kcal. It should also be pointed out that the secretion of the sweat glands has its physiological limit. When this limit is reached, no matter how much water and salt are supplied, no sweat will be produced. Besides, the secretion of the sweat glands will be inhibited while the skin is wet.

The speed of sweat vaporization also depends on the water content in the air and the air convection. When the humidity is high, the vaporization is very slow and vice versa. If the air flow or air convection is fast, the vaporization can be very fast. The reason why a fan can cool people down is that it improves the air convection and further increases the sweat vaporization. Individuals will feel discomfort in high humidity and high temperature weather but not in dry, hot weather. This is due to the difference in sweat vaporization. There is no water content or air conduction or convection in outer space; therefore, the importance of vaporization of sweat becomes more significant. This subject deserves more concern.

#### 4) Striated muscles

Striated muscles make up half the body's weight. The contraction and tension of the striated muscles produce a large quantity of heat which comprises 70% of the heat produced by the metabolism. The contractions of the striated muscles are voluntary, and the tension and some other activities are reflex-oriented.

Under normal conditions, the involvement of the striated muscles in temperature regulation is voluntary, but some of their functions change gradually from voluntary to automatic. When the environmental temperature is low, people engage in all kinds of muscle activities to produce heat. When body temperature drops below  $36^{\circ}\text{C}$ , local shivering or goosepimples can be observed. Shivering is a reflex, not a voluntary response. From the physiological point of view, this is a compensatory response which tries to stop the decrease of body temperature. The shivering first occurs only in local muscles, starting with the jaws, then the limbs. During this stage, the shivering can still be controlled by one's will. The body temperature will gradually recover, and the shivering will stop. However, if an individual has to be in cold sea water for a length of time, e.g. following a crash, heat loss will be 10 times faster than in air. This will drop body temperature to an extremely low level. In such a situation, shivering can spread throughout the body and cannot be consciously controlled. This type of shivering is usually intermittent. The more serious the shivering, the shorter the intermittence will be. This kind of shivering is not purely a reflex; it may very well (but not yet certainly) be triggered by the impulse sent out from the nuclei nervorum cerebralis<sup>1</sup> to the low-level motor cell. Besides, the cold stimulus will directly cause the muscle to contract and to cramp.

##### 5) Endocrine gland and cell metabolism

It is well known that appetite and calorie requirement will increase in winter. It has been proven in animal experiments that the thyroid gland and the adrenal medulla will function more actively in cold weather, and the metabolic rate will be increased. The anterior pituitary gland receives the message from the cold receptor and sensory centers and releases thyroid-stimulating

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<sup>1</sup> It has the function of adjusting posture, muscle tension, coordination, etc.

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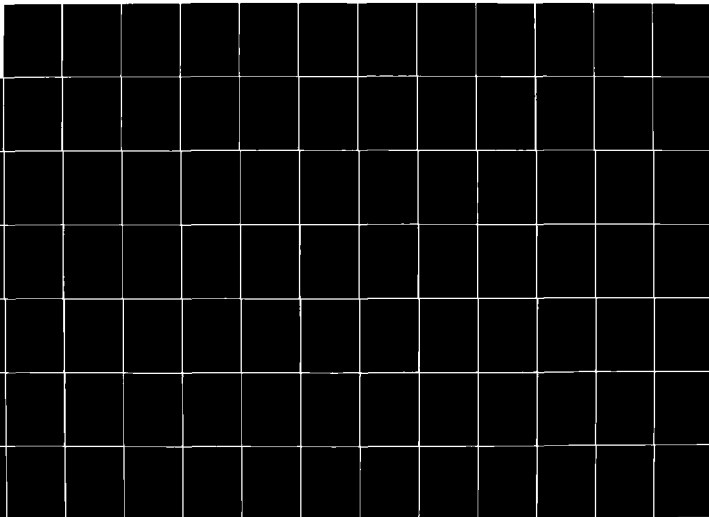
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hormones which stimulates the secretion of the thyroid gland. The results of these animal experiments can offer an explanation for enhanced metabolism in cold weather.

The secretion of the adrenal medulla, adrenaline and noradrenaline, can increase heat production. It is obvious that cold stimulates not only the secretion of the thyroid gland but also that of the adrenal medulla (through the reflex of the sympathetic nerve). The heat is produced through the tension of the striated muscle, contraction of the smooth muscle of the internal organs and increased carbohydrate metabolism.

The adrenal cortex usually shows a series of responses to cold and heat stimuli, but whether it is related to temperature regulation remains unknown.

#### IV Physiological Heat Indicator

Degrees are the heat unit used in physics, for direct reflection of the temperature of the environment. However, the effect of temperature on the human body depends not only on the environmental temperature but also on other factors such as the flow rate and temperature of the atmosphere. We have to take all the factors into account when we study the effect of temperature on human beings. Some temperature indicators used in medical physiology can reflect the combining function of temperature, air flow rate and humidity, as a whole, which can indicate the real effect of temperature indicators on human beings. Unfortunately, these indicators will only work within a certain temperature range. These indicators are often called "physiological heat indicators". More than ten are commonly used, but we will introduce only four:

1. Effective temperature (ET)

This is a temperature indicator set up according to the

individual's experience with temperature. It combines the effects of temperature, humidity and air flow rate and is an equivalent temperature at the lowest air flow and saturated humidity. The environmental temperature can be converted to effective temperature by using Figure 4-4 and Table 4-3. For example, draw a straight line between  $40^{\circ}\text{C}$  dry bulb temperature and  $30^{\circ}\text{C}$  wet bulb temperature, and its intersection with the curve of the air flow of 3 m/sec is the corresponding Effective Temperature.

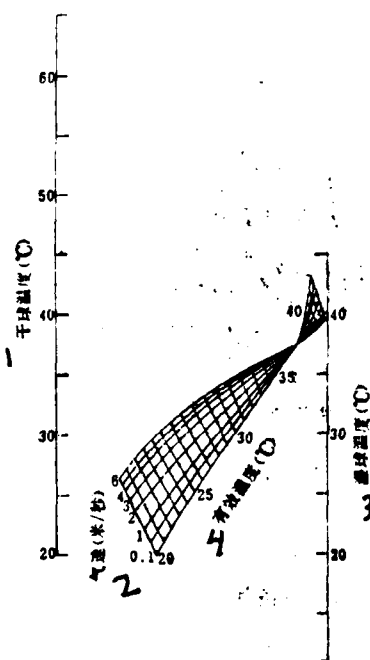


Figure 4-4. Effective Temperature under different air flow rate, research subjects wearing normal indoor clothing: 1) dry bulb temperature,  $^{\circ}\text{C}$ ; 2) air flow, m/sec; 3) wet bulb temperature,  $^{\circ}\text{C}$ ; 4) Effective Temperature.

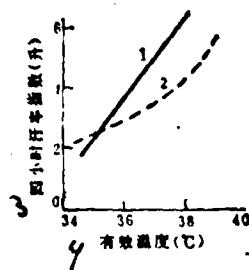


Figure 4 - 5. Relationship between Effective Temperature and  $P_4S_R$ : 1) exposed to wet, hot weather; 2) exposed to dry, hot weather; 3)  $P_4S_R$ , 1; 4) Effective Temperature, °C.

TABLE 4-3. EFFECTIVE TEMPERATURE (ET)

DRY BULB TEMPERATURE	RELATIVE HUMIDITY (%)				
	60	70	80	90	100
10	50	50	50	50	50
16	58	59	59	60	60
21	67	67	68	69	70
24	71	72	73	74	75
26	75	76	77	79	80
29	79	80	82	83	85
32	83	85	86	88	90
35	87	89	91	93	95
37	90	93	95	98	100

2. Perspiration rate per four hours. ( $P_4S_R$ )

Using the perspiration rate/4 hours under different hot environments as an indicator, effective temperature can be converted into  $P_4S_R$  using Figure 4-5.

3. Dry-wet-black bulb temperature.

Temperatures are taken respectively by the dry, wet and black

bulb thermometers. The weighted average of these temperature values can be used as a physiological heat indicator. Three main types are discussed:

- 1) Wet-black-dry bulb temperature (WGBT):

$$\text{WGBT} = 0.7 T'_{wb} + 0.2 T_g + 0.1 T_a \quad (1)$$

$T'_{wb}$  : Temperature taken by a wet bulb thermometer which is not placed in artificial ventilation conditions.

$T_g$  : Temperature taken by a black bulb thermometer.

$T_a$  : Temperature taken by a dry bulb thermometer.

- 2) Wet-black bulb temperature (WBGT):

$$\text{WBGT} = 0.7 T_{wb} + 0.3 T_g \quad (2)$$

$T_{wb}$  : Wet bulb temperature.

$T_g$  : Black bulb temperature.

- 3) Wet-dry bulb temperature (WD):

$$\text{WD} = 0.85 T_{wb} + 0.15 T_a \quad (3)$$

The maximum endurance to heat can be calculated as follows:

$$\text{WD} = 0.9 T_{wb} + 0.1 T_a \quad (4)$$

This physiological heat indicator can be used under various con-



ditions, such as different air flow rate, degree of exercise and clothing.

4) Operating temperature (OT or  $T_o$ ):

The operating temperature can be calculated as follows:

$$T_o = \frac{h_r T_w + h_c T_a}{h_r + h_c} \quad (5)$$

$T_w$ : Wall temperature.

$T_a$ : Atmospheric temperature (dry-bulb temperature).

$h_r$  and  $h_c$  : Coefficient of heat radiation and heat convection.

## Chapter 16 Comfortable Temperature and Tolerable Temperature

### I Introduction

What range of temperatures will make people feel comfortable? During passenger flights or space travel, the cabin temperature is kept in a range comfortable for the crew and passengers. However, this "comfortable" temperature range cannot always be maintained due to accidents or some special research needs. Fighters always have to sacrifice comfort for speed, since any complicated temperature regulation facilities can add extra weight and volume to the plane, which will slow it down. The comfortable temperature range required to maintain flying ability and operational efficiency is called the "acceptable temperature". The comfortable, tolerable and acceptable temperatures will all be discussed in this chapter.

## II Comfortable Temperature

### A. Range

"Comfortable temperature" refers to the temperature range within which an individual will subjectively feel comfortable. Not only the environmental temperature but also other factors contribute to this subjective feeling. Within a certain temperature range, the lower the environmental temperature and higher the air flow rate, the higher the comfortable temperature can be. Individuals with heavy clothing, strong physical strength and good adaptation ability to cold will need lower comfortable temperatures. The above factors have to be taken into account in order to get reasonable upper and lower limits of the comfortable temperature range.

While determining the comfortable temperature range, the factors which may affect the comfortable temperature range have been well defined in physiology: clothing, one layer of clothes (equivalent to one insulation unit<sup>1</sup>): relative humidity, 50%; wind speed, 100 cm/sec; gravitation, 1 G; atmospheric pressure, sea level; no experience of heat or cold adaptation, etc. Under these defined conditions, the comfortable temperature is usually around 21°C, which is equivalent to the skin temperature<sup>2</sup> of 33-34°C. the range of comfortable temperatures is shown in Figure 4-6.

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<sup>1</sup>Insulation unit is a way to measure the heat capacity of clothes. One insulation unit is defined, in physics, as the resistant ability of heat conduction of 1 Kcal/m<sup>2</sup>.hr.0.18°C. Its physiological meaning is: 1) when a seated, resting man with average-weight underwear, shirt, pants, socks and shoes feels comfortable with his surrounding temperature; or 2) when a seated, resting individual feels comfortable at 21°C (relative humidity of 50%, air flow of 100 cm/sec); the insulation value of his clothes is defined as one insulation unit.

<sup>2</sup>Skin temperature is the temperature of skin. Skin temperature varies among different parts of the body. Skin temperatures are usually taken at the forehead, arms, the backs of the feet and neck, with the average of these figures considered to be the "skin temperature."

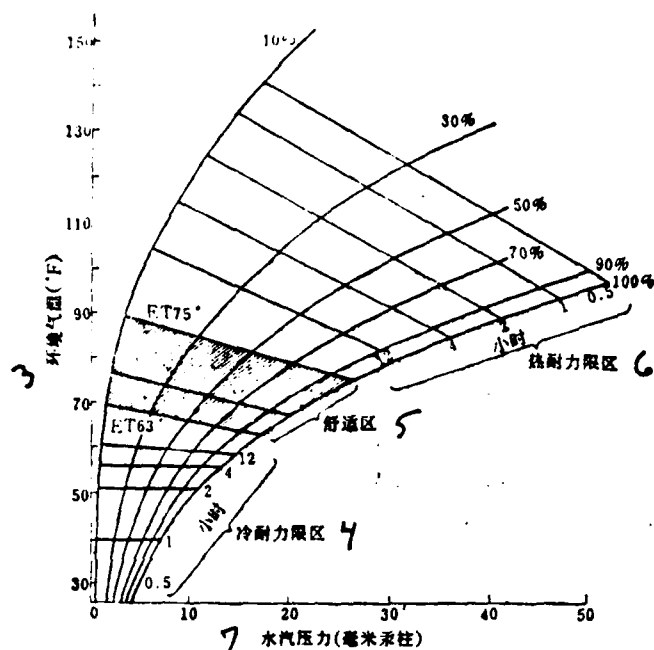


Figure 4-6: Comfortable temperature and tolerable temperature:  
 1) air flow, 15-25 /min; 2) individual being seated, with one in-  
 insulation-unit clothes, mild hand movements. ET (effective tempera-  
 ture) %, on the top of the curve, indicates the relative humidity -  
 one-half hour, one hour, two hours, four hours, 12 hours indicate the  
 duration of the stay; 3) atmospheric pressure, °F; 4) cold-tolerable  
 range; 5) comfortable; 6) heat-tolerable range; 7) vapor pressure, mmHg.

TABLE 4-4. EFFECT OF VAPORIZATION HEAT LOSS  
 ON COMFORT

PERCENTAGE OF TOTAL VAPORIZATION HEAT LOSS (%)	DEGREE OF COMFORT
0 - 10	Feeling chilly
10 - 25	Feeling comfortable
- 70	Tolerable
70 - 100	Too hot
> 100	Dangerous

TABLE 4-5. COMFORTABLE SKIN TEMPERATURE  
AT DIFFERENT PARTS OF THE BODY

PART OF THE BODY	COMFORTABLE TEMPERATURE (°C)
1) Head, chest, abdomen, back, hip	34.6
2) Thigh, upper arm	33.0
3) Calf, forearm	30.8
4) Hand, feet	28.6

For a comfortable temperature, the skin temperature of head and feet can have a 6°C difference.

1. Latent heat loss through vaporization

Heat loss by vaporization will increase in hot weather and decrease or be close to zero in the cold weather. Even within the comfortable temperature range, a small amount of vaporization still exists though not easy to detect. This is called latent heat loss through vaporization and also unconscious perspiration. This heat loss makes up approximately 10-25% of the maximum heat loss through vaporization. This can be used as an objective basis for determining a comfortable temperature (Table 4-4). Heat loss by vaporization varies among different parts of the body; therefore, the comfortable temperature will be different for each part. The difference is shown in Table 4-5.

2. Energy balance indicator

When the environmental temperature is too high or too low, it is difficult to keep the balance between the internal (body) temperature and the external (environmental) temperature. Therefore, the cold-debt (excessive storage of heat) and heat debt (excessive heat loss) will occur. On the other hand, if the body

temperature can be regulated to zero cold- and heat-debt, the environmental temperature can then be considered as the comfortable temperature. As the energy is balanced, an equation can be set up as follows:

$$H_p - (R + C + D + E) = 0 \quad (6)$$

$H_p$  : Heat production.

$R$  : Radiation heat.

$C$  : Heat loss through convection.

$D$  : Heat loss through conduction.

$E$  : Heat loss through vaporization (at comfortable temperature,  $E$  is latent vaporization heat)

unit : Watt/m<sup>2</sup>

It can be concluded from our experience that the energy balance under operational conditions at 25-29°C and the physical working condition at 19-21°C is equivalent to that of being naked.

#### B. Effect of Individual Background on Comfortable Temperature

This is a rather complicated topic. There is no regular pattern which can be followed. Here, we will only briefly introduce these factors.

##### 1. Activity

The comfortable temperature range while resting is very

similar to that of carrying out mild activities while seated. Heavy physical activities will cause the comfortable temperature range to drop (Table 4-6).

TABLE 4-6  
COMFORTABLE TEMPERATURE<sup>1</sup> RANGE FOR RESIDENTS  
IN NORTHERN TEMPERATE ZONE WHO DRESS IN WINTER  
CLOTHING AND ENGAGE IN VARIETY OF ACTIVITIES

ACTIVITIES	OPERATING TEMPERATURE (°C)	DRY BULB TEMPERATURE (°C, taken from wet wall)
Complete rest	25.6	26.1 - 26.7
Mild activities	23.3	23.9 - 24.4
Fast typing, etc.	20.0	20.6 - 21.1

<sup>1</sup>Humidity was not considered, because its effect at this temperature is nonsignificant.

## 2. Clothing

As shown in Table 4-7, a lower comfortable temperature is required for individuals who wear heavy clothes. It is also indicated in this Table that the comfortable temperature at zero gravity is similar or slightly lower than at 1G.

## 3. Zoning

Requirements for a comfortable temperature is different for individuals from different areas and with different adaptations.

## 4. Sex and age

Generally speaking, the comfortable temperature for females is 0.55°C higher than that for males. It is 0.55°C higher for people over 40 than for youngsters. The comfortable temperature for older people is even higher.

TABLE 4-7. COMFORTABLE TEMPERATURE FOR DIFFERENT CLOTHING AND ACTIVITIES

ATMOSPHERIC PRESSURE	WIND SPEED	GRAVITATION (G)	METABOLIC RATE (Kcal/hr)	INSULATION VALUE OF CLOTHING (INSULATION UNIT)	INSULATION VALUE OF THE AIR (INSULATION UNIT)	COMFORTABLE TEMPERATURE (°C)	
760	With ventilation system  (100 cm/sec)	1	90 <sup>1</sup>	1.0	0.4	25	
			270	0.5	0.4	15	
0			90	1.2	0.5	24	
			270	0.6	0.5	11	
		380	No ventilation system	90	2.4	0.5	18
				270	0.6	0.5	11
1	90			1.2	0.8	23	
	270			0.6	0.5	12	
0	90	2.4(?)		(?)	(?)		
	270	0.6		0.5	11		

<sup>1</sup>Metabolic rate of 90 Kcal/hr is equivalent to being seated and resting; 270 Kcal/hr is equivalent to mild physical activity.

### III. Endurance of High Temperatures

The limit of heat endurance can be shown as two types: 1) skin type: the occurrence of intolerable pain by the skin until the skin burns. This limit of heat endurance is called skin heat endurance; 2) overall type: occurrence of discomfort over the whole body, due to high temperature, until cramps and collapse occur.

If the individual is exposed locally to intensive heat for less than 10-30 minutes, only skin-type endurance will be involved. In this situation, the pain of skin burn will cause the individual to take escape measures even before the overall type symptoms occur, such as discomfort, cramp and collapse. If the heat exposure area is more than half the body surface, the duration is longer than 10-30 minutes and the heat is not intense enough to cause skin pain, we are dealing with overall type heat endurance. The relationship between skin type and overall type under different conditions is shown in Figure 4-7.

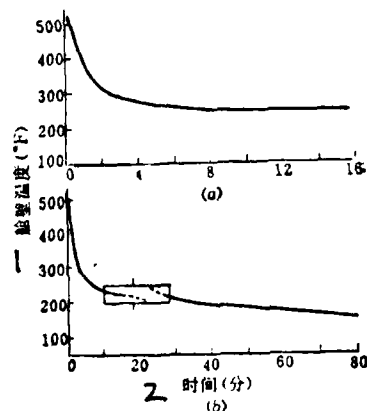


Figure 4-7. Comparison of skin type and overall type heat endurance: a) skin type heat endurance; b) curve on left is reduction of "a" and curve on right is overall type heat endurance; "1" indicates intersection area of both curves; 1) temperature of cabin surface, °F; 2) time, minute.



## A. Skin Heat Endurance

When the skin is heated to a certain temperature (by heat radiation or heat conduction) it will start to suffer pain. The point after which heat will cause pain is called the skin burning pain threshold. The pain will be aggravated as the temperature continues to increase until it cannot be tolerated further, which is the point called subjective tolerable limit of burning pain. Beyond this limit, the skin will start to show burning wounds. The temperature at which burns will appear is called the burning limit or burning injury threshold of the skin.

### 1. Skin burning pain threshold

The skin burning pain threshold of the hand varies greatly among individuals as it also does in different parts of one's body. The pain is a subjective feeling and depends on timing and on the background of the individual. The lowest threshold can be  $36^{\circ}\text{C}$  (skin temperature) and the highest  $47^{\circ}\text{C}$ . The reason for such a wide range is that the skin is sensitive to heat stimulus and can easily adapt to it. The endurance of pain varies greatly among individuals, as well.

The skin burning pain threshold is highly correlated with parts of the body. As shown in Table 4-8, endurance of pain is best on the forehead, less on the arms and varies greatly for palms. The difference is generally within  $1\text{-}2^{\circ}\text{C}$ . The skin burning threshold for heat radiation over the entire body is usually lower than that for local heat radiation.

Burning pain will to a certain degree cause voluntary response; e.g., burning pain in the hand will cause the hand to retract. The response varies among individuals and under different situations. While one person may retract his hand just as he feels the pain, another may not react at all to the same stimulus. The number of individuals who start to feel pain and retract their hands at a certain level is shown in Figure 4.8.

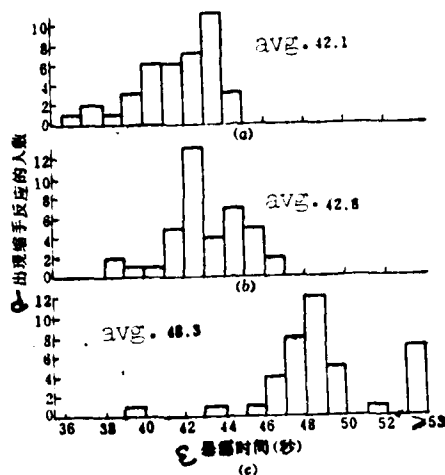


Figure 4-8. Threshold at which pain will cause hands to retract: a) skin not darkened; b) skin darkened; c) tolerable limit; d) number of individuals who retract their hands; e) duration of exposure, sec.

## 2. Subjective tolerable limit of skin burning pain

The subjective tolerable limits of burning pain caused by radiation heat or contact heat on palms, forearm and forehead are listed in Table 4-9 and Table 4-10. The subjective tolerable limit of pain while the whole body is exposed to heat radiation is shown in Figure 4-9.

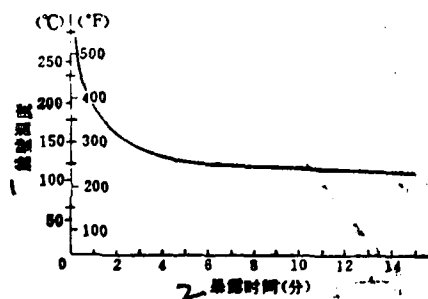


Figure 4-9. Subjective tolerable limit of skin burning pain while suddenly exposed to certain cabin temperatures: 1) temperature of cabin surface; 2) duration of exposure, min.

TABLE 4-8  
PAIN THRESHOLD FOR VARIOUS PARTS OF THE BODY  
WHILE EXPOSED TO HEAT

PARTS OF THE BODY	PAIN THRESHOLD (SKIN TEMPERATURE °C)
Palm	41 - 44
Arm	42 - 43
Undarkened arm	42 - 43
Forehead	42 - 45
Darkened arm (using India ink)	43 - 44

NOTE: Mild pain and no injury under 44°C skin temperature, feeling of serious and intolerable pain at 45°C; occurrence of skin burn at 50°C (10 seconds).

TABLE 4-9  
PAIN THRESHOLD OF FOREARM UNDER HEAT RADIATION  
(TOLERABLE LIMIT OF SKIN BURNING PAIN)

HEAT INTENSITY	2.0	2.33	2.66	3.33	4.0	8.0	16.0
DURATION OF EXPOSURE	>10分 <sup>1</sup>	>10分 <sup>1</sup>	225秒 <sup>2</sup>	115秒 <sup>2</sup>	70秒 <sup>2</sup>	16秒 <sup>2</sup>	7秒 <sup>2</sup>
SKIN TEMPERATURE OF FOREARM	41.5	43.9	45.6	45.1	43.8	44.1	45.5

KEY: 1) minutes; 2) seconds.

TABLE 4-10  
TOLERABLE PAIN THRESHOLD OF THE BACK  
FOR DIFFERENT EXPOSURE (HEAT RADIATION) AREAS

HEAT INTENSITY (cal/cm <sup>2</sup> min)	DURATION OF EXPOSURE (MIN)						
		2.0	3.0	4.0	6.0	8.0	10.0
EXPOSURE AREA (cm <sup>2</sup> )							
35		>240	—	38.4	17.5	11.7	7.5
105		180	—	37.1	15.0	8.1	5.9
210		188	46	25.7	13.4	7.5	5.1

The relationship between the subjective tolerable limit of skin burning pain and the temperature increase rate and clothing is shown in Figure 4 - 10.

The dryness of the skin has a certain effect on the tolerable limit. As the cabin is exposed to heat radiation and the temperature increase rate of the cabin wall is 28-56°C/min, dry skin (skin temperature 44-45°C) cannot stand the pain caused by the 60-70°C environmental temperature for even one minute, but wet skin can stand the environmental temperature of 144°C for 2-3 minutes while suffering pain.

### 3. Threshold of skin burn damage

The threshold for causing burn blisters is much higher than the pain threshold and the subjective tolerable limit. The development of burn injury at different stages is shown in Figure 4-11.

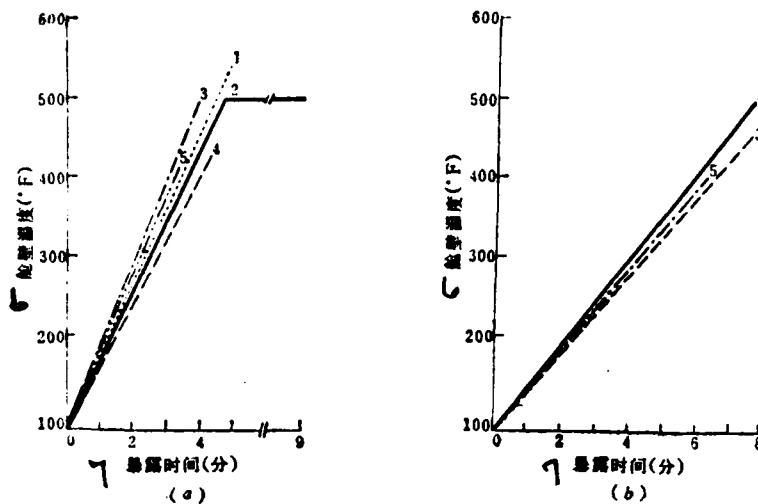


Figure 4-10. Effect of temperature increase rate of cabin wall and clothing on subjective tolerable limit: a) temperature increase rate of cabin wall is 80-95°F/min; b) temperature increase rate of cabin wall is 50-60°F/min; 1) with heavy pilot's suit; 2) with aluminum-coated jacket, helmet and boots; 3) with light pilot's suit; 4) with cotton underwear; 5) naked, control; 6) temperature of cabin wall. 7) duration of exposure (minutes)

The intensities of causing blister and burning pain are shown in Figure 4-12.

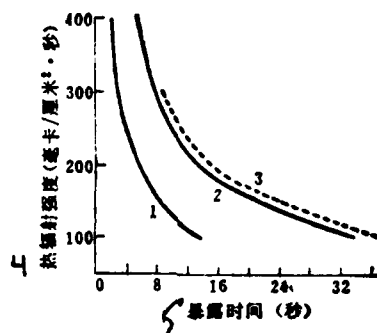


Figure 4-11. Intensity threshold for causing burning pain and blisters: 1) threshold of burning pain; 2) blisters start to appear; 3) blisters alive over skin surface; 4) intensity of heat radiation, mcal/cm²sec; 5) duration of exposure, seconds.

A skin burning injury possesses the following characteristics: 1) when the skin temperature is higher than 44°C, injury of the basic skin structure will appear, no matter how long the duration

of exposure; 2) incidence of injury increases logarithmically with rise of skin temperature; and 3) overall injury includes the injury occurring both during the heating period and the cooling period.

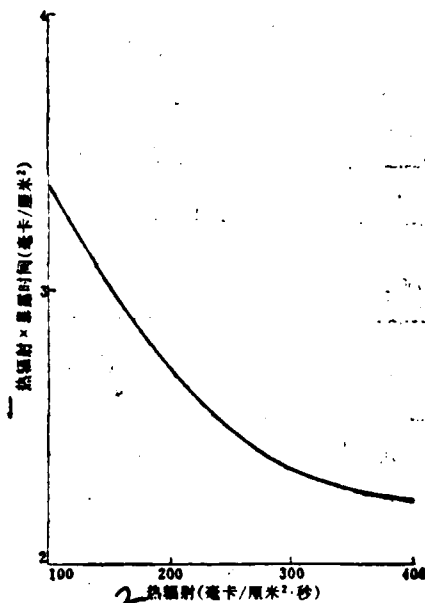


Figure 4-12. Intensity threshold for causing blisters (heat radiation): 1) heat radiation x duration of exposure, mcal/cm<sup>2</sup>; 2) heat radiation, mcal/cm<sup>2</sup> sec.

#### B. Subjective Tolerable Limit of the Whole Body Heating (overall type heat endurance)

This is the limit one can tolerate while being exposed to a high-temperature environment. Relationships between clothing, activity, dryness of skin and this tolerable limit are shown in the following figures:

- 1) Tolerable limits to high temperature while resting, naked or half naked, are shown in Figure 4-13.
- 2) Endurance of high temperature while resting, with different clothing on, is shown in Figure 4-14.

- 3) Dryness of skin, wind speed, environmental temperatures, humidity and atmospheric pressure also have certain effects on temperature endurance.
- 4) Physical activity also affects the endurance of heat, as shown in 4-15 and 4-16.

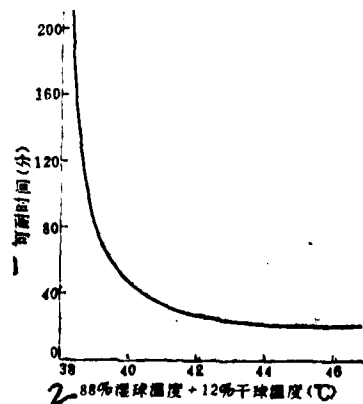


Figure 4-13. Endurance of high temperature while resting (seated): 1) tolerable duration, min; 2) 88% wet bulb temperature + 12% dry bulb temperature, °C.

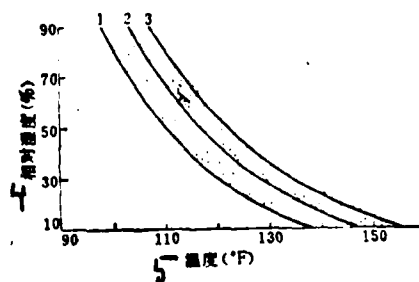


Figure 4-14. Endurance of high temperature while resting, for individuals with underwear, cotton flying suit and socks: 1) tolerable; 2) between "tolerable" and "intolerable"; 3) intolerable; 4) relative humidity, %; 5) temperature, °F.

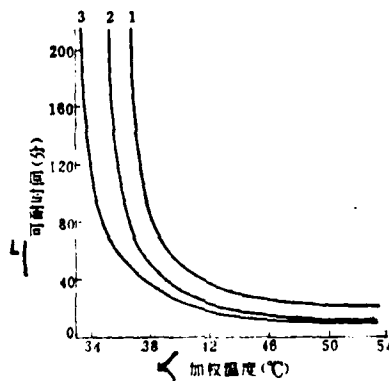


Figure 4-15. Endurances of heat while resting, standing and exercising: 1) endurance at rest, seated (weighted temperature is 0.88 wet bulb temperature + 0.12 dry bulb temperature); 2) endurance at resting, standing (weighted temperature is 0.95 wet bulb temperature + 0.05 dry bulb temperature); 3) endurance at exercising (heat production during exercise is 280 Kcal/hr, weighted temperature is 0.9 wet bulb temperature + 0.1 dry bulb temperature); 4) tolerable duration, min; 5) weighted temperature, °C.

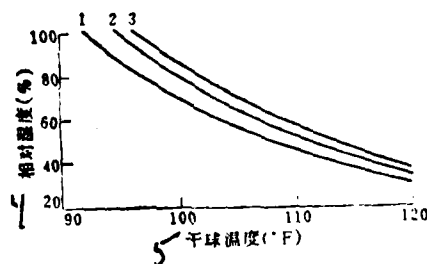


Figure 4-16. Working efficiency during deployment as the indicator of the heat endurance: 1) good working efficiency; 2) difficulty in working; 3) non-workable condition (deployment for 4 hours load, 9.1 Kg — speed, 4.8 Km/hr); 4) relative humidity, %; 5) dry bulb temperature, °F.

The subjective tolerable limit to heat is different under different conditions. For example, the cabin temperature of a passenger flight should not exceed the tolerable limit (at rest) when the temperature regulatory system is out of order. Under the same accident condition, the temperature should not be higher than the tolerable limit during exercise for crew members.



### C. Physiological Endurance of High Temperature

The physiological endurance is the limit over which some abnormal physiological reactions will occur. The criteria used as indicators of physiological endurance of high temperature are discussed as follows:

#### 1. Heart beat rate:

The subjective tolerable limit to heat, in terms of heartbeat, is 120-140 times/min. The physiological endurance is 160 times/min.

#### 2. Internal body temperature:

Rectal temperature usually represents internal body temperature. The subjective tolerable high temperature limit is 38.4-38.6°C in terms of rectal temperature while at rest and 38.5-38.8°C during exercise. The marginal value of physiological endurance is 39.1-39.4°C. As the rectal temperature goes above 39.4°C, it indicates that the perspiration rate and heat conduction on the skin may stop increasing and serious physiological symptoms will start to appear. Clinical high fever cases have confirmed the above predictions.

In addition to the rectal temperature, the increase of rectal temperature of 1.1°C in four hours has also been suggested as the subjective tolerable limit. If the latter criterion is used, the atmospheric temperatures of 42-48°C, 41°C and 38°C are, respectively, the subjective tolerable limits under different relative humidity (>60%, >70%, >90%).

#### 3. Skin temperature:

Skin temperature is a reliable physiological indicator for

burning pain and burning injury. The burning pain threshold is  $41^{\circ}\text{C}$  (skin temperature). The subjective tolerable limit of skin burning pain is  $45^{\circ}\text{C}$  (skin temperature). The burning injury threshold is  $58^{\circ}\text{C}$  (skin temperature).

#### 4. Heat storage:

The total heat storage in the human body can be calculated as follows:

$$Q_{\text{sm}^2} = W_{\text{kg}} \times 0.83 \Delta T_c / A \quad (6)$$

$$Q_{\text{kg}} = 0.83 \times \Delta T_c \quad (7)$$

$Q_{\text{sm}^2}$  : total heat storage for every  $\text{m}^2$  body surface ( $\text{Kcal}/\text{m}^2$ )

$A$  : body surface area

$\Delta T_c$  : increase of internal body temperature ( $^{\circ}\text{C}$ )

$0.83$  : specific heat of the human body

$W_{\text{kg}}$  : body weight ( $\text{Kg}$ )

$Q_{\text{sKg}}$  : total heat storage per kg body weight ( $\text{Kcal}/\text{Kg}$ )  
( $Q_{\text{sm}^2}$  is more commonly used than  $Q_{\text{sKg}}$ )

Total heat storage at the tolerable limit is shown in Table 4-11.

#### 5. Perspiration rate and evaporation

Individuals will lose the ability to exercise if body water

loss reaches 10-15% of the body weight. Death will occur if dehydration reaches 20% of body weight.

6. Uncomfortable responses at physiological limit:

Symptoms such as dizziness, headache, nausea, vomiting, difficult respiration, heartbeat, extremely high rectal temperature and weakness will occur. The critical limit of these criteria are listed in Tables 4-12, 4-13 and Figure 4-17. Over these limits, certain damage will result.

TABLE 4-11. TOTAL HEAT STORAGE AT TOLERABLE LIMIT

REST, EXERCISE AND ADAPTATION		TOTAL HEAT STORAGE (Kcal/m <sup>2</sup> )	FEELING AND RESPONSE
Unadapted	Sleep	44	Wake up during sleep
	Rest	55-85	Subjective tolerable limit
	Exercise	320 (KJoule/m <sup>2</sup> ·hr)	Heat collapse
Adapted	Mild Activity	84	Subjective tolerable limit
	Strenuous Activity	113	Subjective tolerable limit

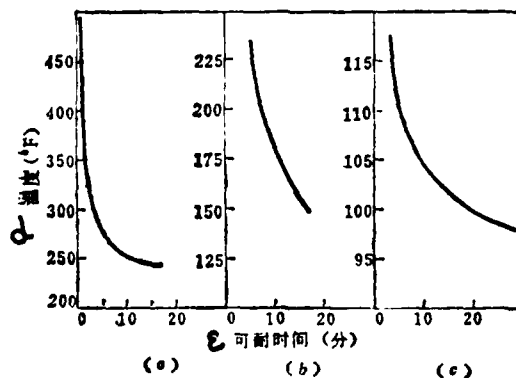


Figure 4-17: Tolerable limits of high temperature expressed in different physiological criteria: a) tolerable limit of skin burning pain; b) tolerable limit using heat storage as indicator; c) occurrence of discomfort (headache, nausea) as the indicator of tolerable limit; d) temperature, °F; e) tolerable duration, min.

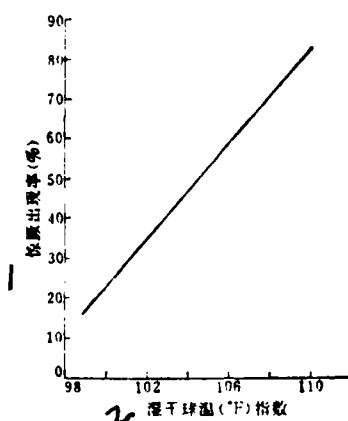


Figure 4-18. Temperature at which fainting occurs. (The wet-dry-temperature WD is 0.85 wet bulb temperature +0.15 dry bulb temperature): 1) incidence rate of fainting, %; 2) WD temperature, °F.

TABLE 4-12. PHYSIOLOGICAL ENDURANCE OF HIGH TEMPERATURE AT REST\*

TEMPERATURE CONDITION (WD, °C)	TOLERABLE DURATION (min)	PERCENTAGE OF INDIVIDUALS WHO CANNOT TOLERATE THIS
36.7	142	30
37.8	78	35
38.3	78	25
38.9	72	30
39.4	67	30
40.0	60	22
40.5	46	40
41.1	44	90
41.6	41	53
42.1	28	55
42.7	20	100
43.8	27	89
46.2	19	80

\* Criteria used as indicators of physiological tolerable limits are: high heartbeat, excessive pulmonary gas exchange, nausea, vomiting. It is indicated in this Table that about 50 % of the individuals cannot stand WD 45°C for more than 41 minutes.

TABLE 4-13  
PHYSIOLOGICAL ENDURANCE OF HIGH TEMPERATURE WHILE EXERCISING \*

TEMPERATURE (WD, °C)	TEMPERATURE (WBGT, °C)	TOLERABLE DURATION FOR HALF OF TESTED POPULATION
32.7	33.1	180
33.9	35.5	97
34.9	34.7	61
35.8	36.6	45
36.3	37.5	44
36.7	36.8	36
38.1	38.9	28
37.8	39.0	26

\* Tested individuals are first exposed to DB 49°C (dry bulb temperature) and WB 27-32°C (wet bulb temperature) for five days. Activity performed during the tolerance test is walking under the following conditions: speed, 5.6 Km/hr; slope, 3%; duration of exposure to heat, 4 hours; rest for 5 minutes after walking for 25 minutes. The physiological endurance indicator is 180 times/min. for heartbeat and 39.2°C for rectal temperature.

#### 7. Dangerous symptoms

Fainting and collapse are dangerous signs which may cause mortality. Temperature limits which may cause fainting and collapse are listed in Figure 4-18 and Tables 4-14 and 4-15.

Most of the people will die in one hour after their internal body temperature reaches 43.3°C and total heat storage is 100 Kcal/m<sup>2</sup>.

TABLE 4-14. INCIDENCE RATE OF FAINTING CAUSED BY HEAT

TEMPERATURE (dry bulb/wet bulb) (°C)	AIR FLOW (Km/hr)	AVERAGE TOLERABLE DURATION <sup>1</sup> (min)	INCIDENCE OF FAINTING (%)
41.1/36.7	4.8	173	20
40.6/37.8	4.8	96	30
40.6/38.3	4.8	71	30
46.1/37.8	4.8	67	30
41.7/40.6	4.8	49	50
54.4/38.9	4.8	46	50
54.4/38.9	4.8	37	60
54.4/40.6	16	29	90
46.1/43.9	4.8	27	89

TABLE 4-15. DURATION OF EXPOSURE BEFORE COLLAPSE

TEMPERATURE (dry bulb/wet bulb) (°C)	TOTAL NUMBER OF TESTED <sup>2</sup> INDIVIDUALS	AVERAGE DURATION OF EXPOSURE BEFORE COLLAPSE	AVERAGE DURATION OF EXPOSURE BEFORE HALF OF TESTED POPULATION COLLAPSE
37.5/33.9	31	87	53
38.0/35.3	31	54	33
40.0/36.7	31	44	30
40.0/41.0	31	26	18
53.0/48.3	31	12	9
43.0/35.0	8	55	35
50.0/37.0	8	31	21
53.0/40.0	8	20	16
56.0/43.0	8	15	11
63.0/47.0	8	10	6

<sup>1</sup>Tolerable duration means time taken to reach rectal temperature of 39.2°C, and heartbeat rate of 180 times/min.

<sup>2</sup>All test subjects have never developed adaptation and keep exercising (280 Kcal/hr) through the whole high-temperature period until they collapse.

#### IV. Endurance of Low Temperatures

##### A. Endurance of Low Temperatures on the Skin

The occurrence of injuries as a result of cold weather is an indicator of being over the limit of cold endurance. When freezing is felt by the skin, constriction of peripheral blood vessels can sometimes cause pain. Drastic constriction of peripheral blood vessels will cut off local blood supply and cause oxygen shortage, which will stimulate the nerves surrounding the vessels and cause pain. This pain is similar to that caused by a tourniquet. Soaking in 6°C cold water when naked will soon cause skin pain all over the body. This temperature limit is higher than that causing injury; therefore, the occurrence of pain can be considered a precursor of skin injury.

Freezing temperature is much lower than temperatures causing skin pain, blood vessel constriction or freezing injury. The average local freezing temperature of the body is  $-5.2^{\circ}\text{C} \pm 1.1^{\circ}\text{C}$ . The temperature beyond which injury and pain are suffered is between 5°C and 10°C of skin temperature.

There is a certain correlation between the duration of exposure to cold and the temperature that will cause skin injuries. If duration of exposure to cold is prolonged, the temperature of causing freezing injury is higher. Exposure when naked to 5-10°C (no air flow) for ten days will cause injuries to peripheral tissues.

##### B. Physiological Endurance

###### While the Whole Body is Exposed to Low Temperatures

A cold environment not only causes pain and injuries, but also induces a series of detrimental reactions:

1) Heat loss as an indicator of endurance to cold

It has been generally accepted that mild symptoms will occur when total heat loss reaches 90 Kcal; intermediate symptoms occur when the loss exceeds 125 Kcal, and serious symptoms occur after the loss reaches 180 Kcal. It seems that using heat loss as an indicator of low temperature limit is practical. The temperature of this kind of endurance is shown in Figure 4-19.

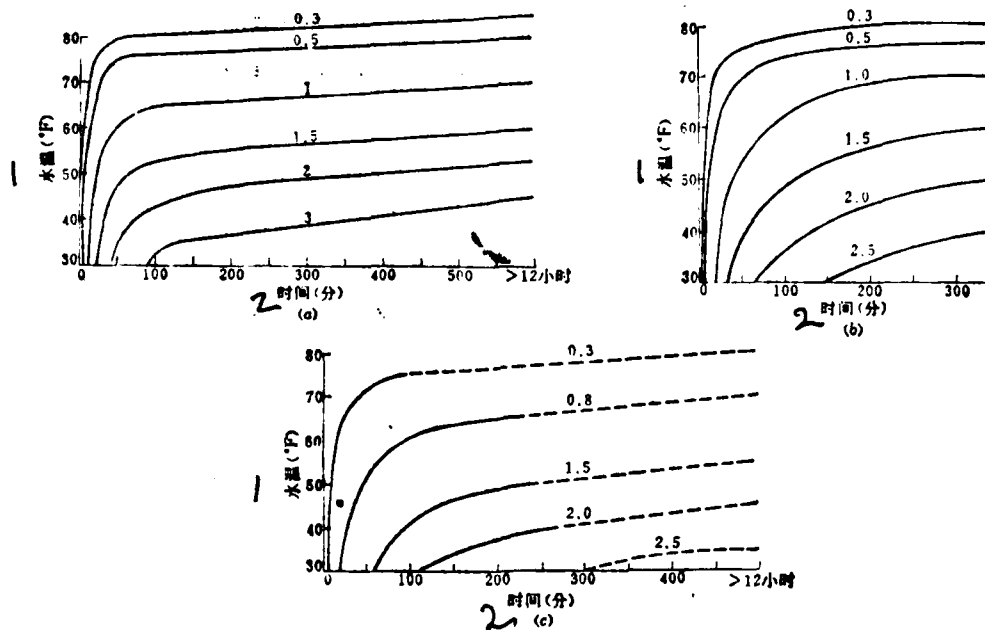


Figure 4-19. Body heat loss as indicator of endurance limit (immersed in cold water): a) heat loss 90 Kcal; b) heat loss 125 Kcal; c) heat loss 180 Kcal; 1) water temperature, °F; 2) time, min.

2) The other criterion is the internal body temperature. Various symptoms which occur at different internal body temperatures are shown in Table 4-16. As the internal body temperature reaches  $34^{\circ}\text{C}$ , no severe symptoms can be observed. If the temperature drops below  $32^{\circ}\text{C}$ , it might cause mortality. Symptoms of different degrees of seriousness appear while the internal body temperature falls to between  $32^{\circ}$  and  $34^{\circ}\text{C}$ .



The endurance of cold can be affected by many factors, for example, mental condition, clothing and activities. Endurance at low temperatures during mild exercise with different clothing is shown in Figure 4-20.

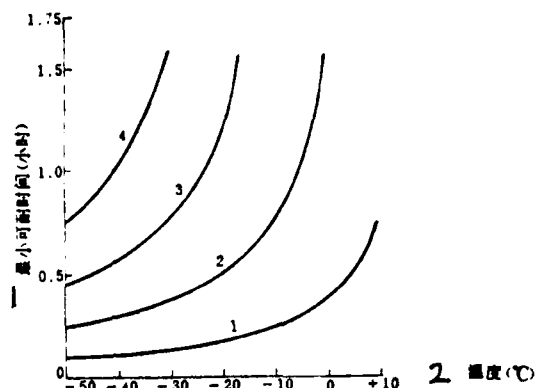


Figure 4-20. Tolerable duration of cold during mild activity with different clothing, using  $40 \text{ Kcal/m}^2$  of heat loss as indicator: 1) min. tolerable duration, hr; 2) temperature,  $^{\circ}\text{C}$ . The figures on the curve indicate insulation units of clothing.

TABLE 4-16. CLINICAL SYMPTOMS AT DIFFERENT INTERNAL BODY TEMPERATURES

SYMPTOMS	INTERNAL BODY TEMP ( $^{\circ}\text{C}$ )	REMARKS
Surviving	$>34.5$	
Forgetful	34	
Numb limbs	32	Naked, immersed in $6^{\circ}\text{C}$ water
Malfunction of heart	$30\sim32$	
Loss of consciousness and death of 50% of test subjects	$30\sim31$	Naked, immersed in $-1.1\sim-6.6^{\circ}\text{C}$ water
Loss of voluntary movability, pupil reflex, skin reflex and muscle tendon reflex:	27	" " " "
majority of people die	$24\sim26$	
100% die	18	

The upper limit and lower limit of tolerable temperature range is shown in Figure 4-21. Figure 4-22 shows the design requirement of cabin temperatures of the airplane, which also indicates tolerable temperature of the human body.

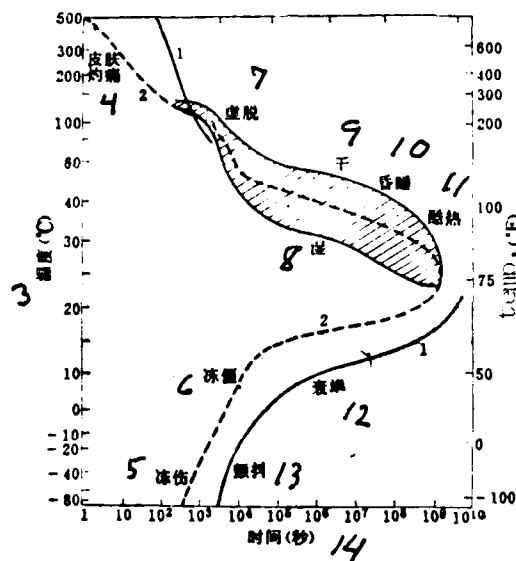


Figure 4-21. Tolerable duration of cold and heat under normal healthy conditions (no ventilation or radiation heat, at rest): 1) with 1-mm thick clothing; 2) naked or partially naked; 3) temperature, °C; 4) skin burning pain; 5) injury by freezing; 6) frozen stiff; 7) collapse; 8) wet; 9) dry; 10) slumber; 11) torturing heat; 12) functional failure; 13) trembling; 14) time, sec.

## VI. Acceptable Temperature

It has been indicated in the introduction that a comfortable temperature cannot be guaranteed under some special conditions during air and space travel. However, for the safety of the passengers and crew members, acceptable temperature range should at least be assured. This temperature is defined in two different ways, as shown in Figures 4-23 and 4-24.

The acceptable temperature range will change if an individual puts on a protective outfit, as shown in Figure 4-25.

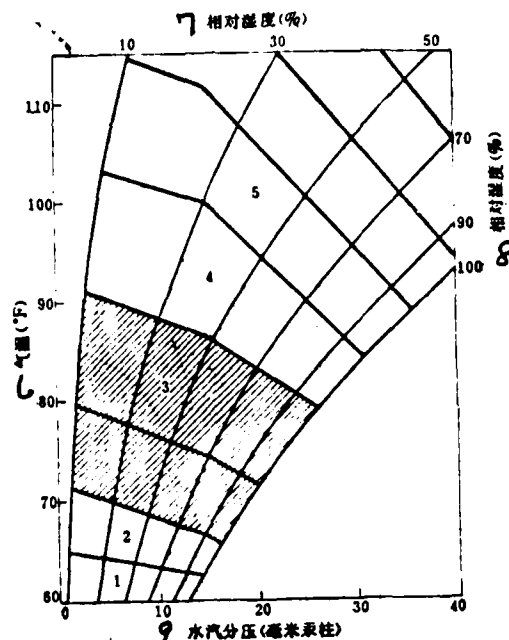


Figure 4-22. Design specification of cabin temperature in airplane: 1) tolerable for 4 hours; 2) tolerable for 12 hours; 3) comfortable; 4) tolerable for 12 hours; 5) tolerable for 4 hours; 6) atmospheric temperature, °F; 7) relative humidity, %; 8) relative humidity, %; 9) vapor partial pressure, mmHg.

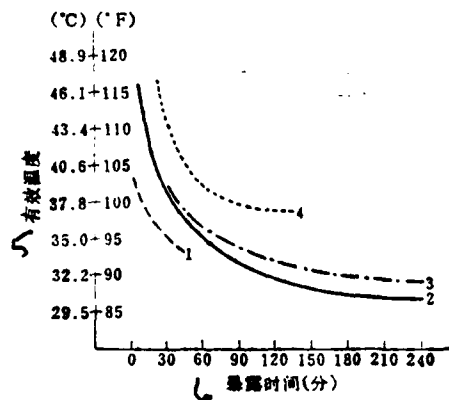


Figure 4-23. Tolerable limits of heat for different criteria: 1) efficiency of complicated jobs not affected; 2) intelligence not affected; 3) suggested physiological tolerable limit; 4) physiological tolerable limit close to sudden occurrence of collapse; 5) effective temperature; 6) duration of exposure, min.

We are more interested in the upper and lower limits of acceptable temperature range than in the range itself. As for working

efficiency, finger manipulation is first and most significantly affected by a cold environment. Therefore, the accuracy of work and flexibility of the fingers can be used as the marginal indicator of the effect of cold temperature on work efficiency. It has been demonstrated in a series of studies that when skin temperature (of the hand) drops below  $15.5^{\circ}\text{C}$ , manipulating efficiency of the hand decreases significantly. Similar results can be found at  $10^{\circ}\text{C}$  environmental temperature. It has been suggested that the torturing heat which will cause the heat storage to be  $42 \text{ Kcal/m}^2\cdot\text{hr}$  (approximately 75% of maximum heat storage) can be considered as the upper limit of the tolerable temperature range.

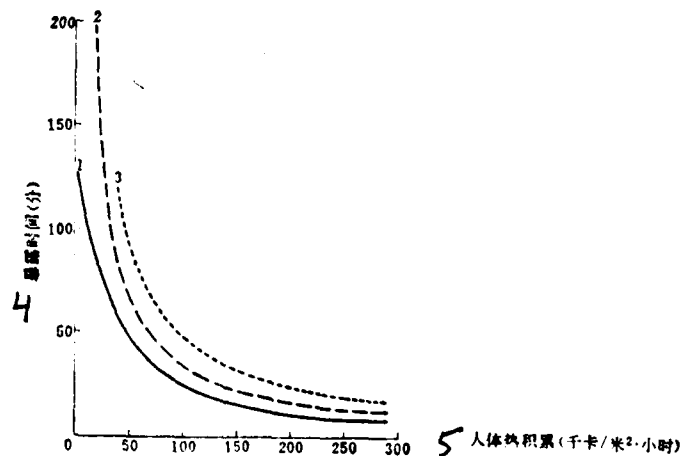


Figure 4-24. Acceptable temperature range and subjective tolerable limit under conditions which will not affect working efficiency: 1) margin beyond which working efficiency will be affected; 2) minimum subjective tolerable limit; 3) average tolerable limit; 4) duration of exposure, min; 5) heat accumulation of human body,  $\text{Kcal/m}^2\cdot\text{hr}$ .

Temperature specification cannot be met necessarily if an accident occurs during air and space travel. However, the physiological functions, at least, should not be endangered under any circumstances. The temperature range that maintains normal physiological functions of the body is called the "safety zone".

It is indicated in Figure 4-27 that when the incidence of heat collapse is lower than 5%, it can be used as indicator of the upper

limit of the safety zone of heat exposure. It can be used as a reference in deciding the upper limit of the safety zone.

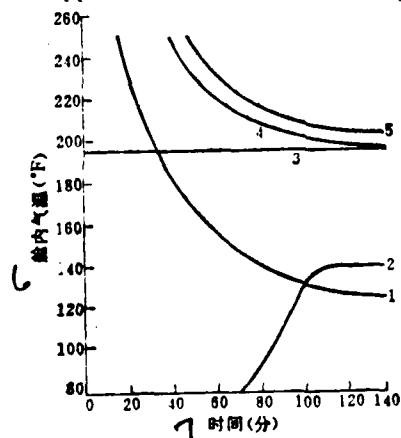


Figure 4-25. Acceptable temperature range while protective outfit is put on or taken off: 1) no protection; 2) high-temperature environment space ship is exposed to; 3) duration of exposure, 3-130 min; 4) limit beyond which working efficiency is affected with ventilated preventive outfit on; 5) tolerable limit with ventilated preventive outfit; 6) cabin temperature, °F; 7) time, min.

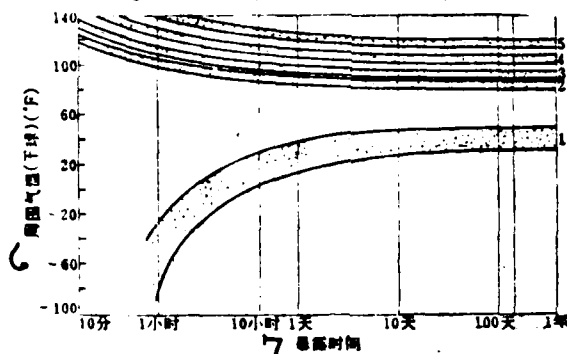


Figure 4-26. Temperature safety zone during rest, with adequate clothing: 1) temperature zone in which injury to extremities can result from cold environment; 2-5) max. tolerable temperature at relative humidity of 100%, 50%, 25% and 10%; over 5) temperature zone at which injury can be caused by high temperature; 6) surrounding temperature, dry bulb temperature, °F; 7) duration of exposure (10 min., 1 hr., 10 hrs., 1 day, 10 days, 100 days, 1 yr.).

The safety zone and tolerable limit are correlated. The safety zone is set up on the basis of tolerable limit and certain safety coefficients. The choice of safety coefficients depends upon actual situations. The safety zone introduced in this section can be used only as a general reference.

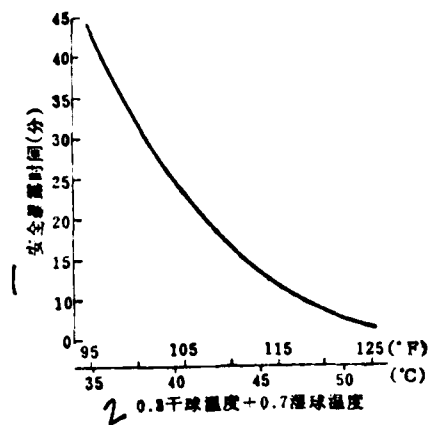


Figure 4-27. Limit of safe heat exposure (unadapted youngsters), incidence rate of collapse lower than 5%:  
 1) duration of safe exposure, min; 2) 0.3 dry bulb temperature + 0.7 wet bulb temperature, °C.

## Chapter 17 The Physiological Effect of Heat and its Prevention

### I. The physiological effect of heat

One significant effect is a hot feeling and perspiration. Other effects, such as the change of heart beat and respiration rate, are not easy to detect. The internal body temperature will increase gradually if the exposure to heat is prolonged, especially while the body starts to lose water and the scorching sun is high up in the sky. If no appropriate treatments are taken, individuals will soon suffer heat-stroke. Extremely hot temperature will decrease the physical strength, and direct sunlight (especially shone on the head) will cause dizziness, nausea, heat-stroke and collapse, and even sunburn. The actual physiological effects of heat and preventive measures are discussed as follows:

#### A. The change of skin temperature and internal body temperature

The skin temperature responds rapidly to the temperature change in the environment. It increases rapidly as the surrounding temperature increases. It shows a linear correlation with the perspiration rate and the heart beat. On the other hand, the internal body temperature acts differently. Within a certain range of high temperature, no change will be observed for internal body temperature. Its response to the cold is also slow. This is just a natural protective mechanism for the internal organs, which has been described in detail in Chapter 15.

The elevation of skin temperature is associated with the heat intake of the skin, and its relationship is shown in Figure 4-28.

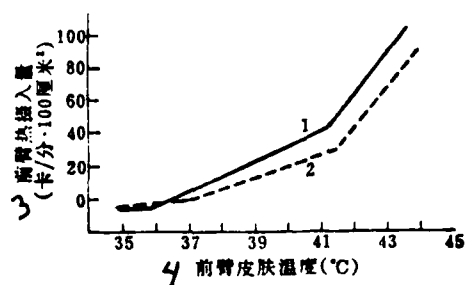


Figure 4-28. The relationship between the heat intake and the elevation of skin temperature.

Key: 1. winter, 2. summer, 3. heat intake of forearm (cal/min. 100cm<sup>2</sup>), 4. The skin temp. of forearm (°C).

It is indicated in the figure that the skin temperature of the forearm is 37-40°C and the heat conductivity of the hand is 5 cal/min. 100cm<sup>2</sup> °C.. As the skin temperature raises above 40°C, the heat conductivity of the forearm is 15 cal/min. 100cm<sup>2</sup> °C, and that of the hand increases to 24 cal/min. 100cm<sup>2</sup> °C. The skin temperature changes corresponding to the fluctuation of the blood flow in the skin.

In contrast to the skin temperature, the internal body temperature responds slowly to the environment. For example, when the environmental temperature raises from 25°C to 60°C, the skin temperature will increase rapidly, but the cranial temperature will not respond until 8 minutes later. If the environmental temperature drops back to 37°C after 30 minutes, the skin temperature will soon decrease at the rate of 0.5°C/min and the drop will gradually level off until the skin temp. comes back to 36.1°C. As for the cranial temperature, it will not respond until 8-9 minutes after the environmental temperature drops back to 37°C. When the environmental temperature is raised to 60°C after 30 minutes at 37°C, the same result will be observed.



Under the heat stress, the internal body temperature depends mainly on the heat storage in the body which is affected by the heat balance. The internal body temperature will increase gradually only when the environmental temperature increases to a certain level and stays at that temperature for a considerable time. The higher the environmental temperature is, the higher the internal body temperature will be. In other words, under the heat stress, the internal body temperature will not respond to the change in the environmental temperature immediately, it will only increase gradually with time. The increase of internal body temperature will be faster and more significant during exercise. How fast the internal body temperature increases depends on the intensity of the activity.

#### B. Perspiration rate

Perspiration is a physiological response to heat. Its function is to increase the heat loss through vaporization and this keeps the body temperature in a constant range. Therefore, perspiration can increase the heat endurance. As the environmental temperature increases, perspiration rate will increase correspondingly, and so does the heat loss through perspiration. In addition to the perspiration over the whole body, local temperature increases on the skin will also cause local perspiration.

Perspiration is the result of a nerve reflex. The functions of the sweat glands over the whole body are regulated by the temperature center in the thalamus. But the perspiration on the forehead can also be affected by the emotions. As the thalamus temperature increases, the heat center will send out a message to the perspiration nucleus in the medulla and the impulse will cause the perspiration over the whole

body through the functioning of the sympathetic nerve. The body starts to perspire when the cranial temperature goes above  $37.1^{\circ}\text{C}$ . For every  $0.01^{\circ}\text{C}$  increase of the cranial temperature, the vaporization rate will increase by 2 cal/sec (The normal heat production is 20 cal/sec). The increase of skin temperature will also induce perspiration through a reflex, but the response is slower and less significant. The heat stimulus on the skin has to travel through the cerebrum before it can reach the thalamus. Therefore, it takes more time and a longer passage for the stimulus on the skin to function the same way (induce perspiration) as the stimulus in the central nerve system.

It was discovered 30 years ago that the perspiration will first increase due to heat, but level off or even decrease after a certain duration. The early scientists suspected that the leveling-off or decrease might result from the exhaustion of the sweat glands. This phenomenon was correlated to the temperature, humidity, and the duration of exposure. After the sweat glands stopped functioning, the correlation between rectal temperature and perspiration rate was destroyed. The latest studies do not agree with this early hypothesis. It is suggested in the latest studies that the inhibition of perspiration is due to the moisture on the skin, not the exhaustion of sweat glands. The sweating will be inhibited as soon as the skin is wet. Therefore, wiping of the sweat will always give one a cooler feeling. As the environmental temperature increases, the vaporization of sweat will decrease, and the sweat will accumulate on the skin and causes the decrease in the perspiration rate and heat loss. The reason why people suffer from heat is not only because of the high temperature, but also due to the inhibition of vaporization because of high humidity in the environment.

The perspiration rate also depends on the water content and the concentration of sodium ion decrease in the blood. Inadequate water supply, and low permeability electrolytes will decrease the perspiration rate.

Profuse perspiration under heat stress will result in excessive loss of the body water and salt, which is one of the important reasons why heat causes severe symptoms. Therefore, adequate water supply and salt supply in hot weather is a very efficient way to prevent accidents.

C. The change of cardiovascular system, respiration, and metabolism

It is well known that heat stress will increase the heart beat. The increase of the heart beat is more significant when the effective temperature exceeds 30°C. When the heart beat is under 120 beats/min, there exists a linear correlation between the increase in the heart beat rate and the rectal temperature. When the heart beat rate is over 120 beats/min, the heart beat will increase faster than the rectal temperature. Therefore, the increase of heart beat rate becomes the bottleneck factor to the endurance of heat when it is over 120 beats/min.

Heat stress will also increase the cardiac output. The cardiac output is 2.5 l/min. at 22. °C, 3.5 l/min at 30 C, and 5-6 l/min. at 40 C. The longer the exposure duration, the more the cardiac output increases. This increase in cardiac output is due to the increase in heart beat, not the increase of cardiac output volume per minutes. When the heart beat exceeds 120 beats/min, the dilation period of heart will be shortened, and the venous blood which flows back to heart will also decrease. Therefore, the cardiac output per minute will not continue to increase. When the heart beat reaches

140 beats/min., the cardiac output per minute will even decrease.

Heat will cause the peripheral blood vessels to dilate, and the resistance in the blood vessels to drop, and eventually a drop of the blood temperature. However, the increase of the heart beat and the cardiac output per minute will increase the pulse pressure, and compensate partially for the drop of the resistance in the peripheral blood vessels. Therefore, the blood pressure will not drop too much during the early stages of the heat stress, but it will drop significantly as the cardiac output decreases significantly.

Heat will cause the blood vessels in the skin and in the muscles to expand greatly. But it will cause the blood vessels in the internal organs to constrict, and force the blood to flow from the internal organs to the skin and muscles. This is an emergency physiological response, which is regulated by a series of nervous and body fluid functions.

The effect of heat on the respiration rate is not significant if the exposure duration is too short (e.g. 10 min), the temperature is not extremely high (e.g. 60°C room temp.), and the activity is not very strenuous (e.g. climbing up and down 15 stairs per minute). However, the respiration rate, exchange volume and the total volume do increase drastically when the environmental temperature is high, the duration of exposure is long and the activity is strenuous. But the permeability of the lung will decrease as the environmental temperature increases. The excessive heat can cause the max.  $O_2$  intake to drop 25% among individuals who are not yet adapted to a hot environment, but this will not be found in an adapted group. The  $O_2$  utilization rate of the blood and tissues will drop from 23% (normal) to 10-15% during the exposure to heat.

The blood composition also changes in the hot environment. The specific albumin volume of plasma, red blood cell counts, acidity and the concentration of lactate all increase during the hot season, which may result from water loss through perspiration. The loss of water and salt in the blood, and the after effects of the water loss through perspiration, are characteristic responses of the blood to the heat stress. It is also suggested that heat may also cause decalcification. When living in a 50°C environment for 5 days, the decalcification can reach 19%. The increase in nitrogen excretion and the decrease in sodium and chlorine excretion can also be observed.

D. Other Effects of Heat

1. The effect on general endurances

Heat affects various endurances in many different ways. For example, heat can reduce the load endurance which will drop 1G below 71°C. As the cranial temperature raises to 38.5°C, the load endurance will drop 0.9G. As the cranial temperature raises to 37.8°C, the load endurance will drop 0.5G. If the internal body temperature is normal and the peripheral blood vessels dilate, the load endurance will drop 0.3G. Heat will also reduce the shaking endurance. Heat aggravates the physiological reactions to O<sub>2</sub> shortage, decreases the physical strength, and reduces the posture change endurance.

2. The effect on flying endurance

The general working efficiency will not be affected by the environmental temperature below 29-30°C, but more complicated operations and alertness will be affected by prolonged exposure to 30-35°C. Above 60°C, the efficiency of any kind

of operation will decrease.

#### E. Sensitivity to Temperature

The distribution of the temperature sensors varies among different parts of skin. For example, the cold- and warm sensors are distributed more densely around the nose tip and less densely on the inner side of the arm. The skin can adapt to the temperature change rather rapidly. Using a metal needle to stimulate the warm sensor on the skin for 1 minute, the feeling of warmth will almost disappear completely at the end of 1 minute. This is called the "sensory adaptation" in physiology. It takes a considerable period to reach complete adaptation. Because the skin can easily adapt to the local temperature change, it cannot easily detect slow changes of temperature. For example, individuals will not be able to sense a temperature change at the rate of  $\pm 10^{\circ}\text{C}/35\text{-}45$  min. (equivalent to  $0.2^{\circ}\text{C}/\text{min}$ ). The local adaptation to temperature cannot represent the adaptation ability of the whole body. It has been reported that the skin can easily adapt to  $20\text{-}40^{\circ}\text{C}$  locally, but as far as the whole body is concerned, the adaptation is only limited to  $32\text{-}35^{\circ}\text{C}$  of skin temperature.

People show different responses to radiation heat and contact heat. If the radiation heat (surface area is less than  $700\text{ mm}^2$ ) can cause feeling, it will only cause pain, not the warm feeling. On the contrary, only  $1\text{ mm}^2$  (or less) of contact heat will be able to cause the feeling of warmth in a certain temperature range and duration.

The feeling of warmth in a large area is different in many ways from that within a small area. From the adaptation point of view, the former is slower and difficult to respond to. For example, the warm threshold of the upper

part of the body will not be affected by the environmental temperature, which means no adaptation is necessary. On the other hand, the adaptable range of the whole body (heating causes the feeling of warmth ) is between 32° and 35°C. When the skin temperature is above 35°C, even an adapted individual will have a hot feeling. If the whole body is exposed to heat, the temperature sensitivity varies among different parts of the body, which depends on the perspiration rate in each individual part.

The exposure to long periods of extreme heat will result in dizziness, headache, vision impairment, nausea, cramp, paleness, sweating, weakness, fatigue, worry, unstable emotions, loss of self-control. Under extreme conditions, collapse, fatigue, dizziness, unconsciousness, and even death may occur. The general physiological responses to heat stress are listed in Table 4-17.

It should be pointed out that the adaptation of skin sensors cannot be confused with the adaptation of the whole body to a specific environment. The former is a local response and happens rather rapidly. The latter is the result of the various regulatory and compensatory responses, which will take a longer time to develop and will not disappear rapidly.

#### F. Heat Stroke

Heat stroke can result when long-term exposure to heat exceeds the tolerable limit. From its pathological characteristics, heat stroke can be divided into the following categories:

TABLE 4-17 The objective and subjective responses to  
different environmental temperatures

Temp.	Results	Duration	Symptoms (Subjective)	Objective Response	Requirement of Protection
120°C (burn- ing hot)	burn	1 sec - 1 min	pain	subjective tolerable limit	keeping cool
95°C (burn- ing hot)	collapse	1 min - 1 hr	dizziness	-	keeping cool
50°C	fatigue	1 hr - 1 day	fatigue	dilation of blood vessels and sweating	permeability required by vaporization
21	comfortable	unlimited	none	-	insulation
-7	fatigue	1 day - 1 hr.	feeling cold	tremor	insulation
+5 (in the water)	frozen stiff	1 hr - 1 min.	frozen stiff	tremor	-
-55 (inside the metal surface)	unconsciousness	1 min - 1 sec	pain	subjective tolerable limit	keeping warm



## 1. Symptoms of over-heating:

This symptom is mainly attributed to excessive heat storage which cannot be dissipated in time. The diagnostic characteristics are: a drastic increase of internal body temperature (rectal temperature can reach 40-44°C); stoppage of perspiration (almost completely): dry and sticky skin. The stoppage of perspiration cannot be attributed to the loss of body water, but some reflex responses. The subjective symptoms are headache, dizziness, nausea, vomiting, palpitation, fatigue, staggering steps, fast heart beat, increase of leukocytes. If the severe symptoms, such as unconsciousness, insanity, are not treated immediately, the brain may be damaged.

Emergency procedures in dealing with the over-heating are:

- (1) Move the patient from the hot environment to a cooler, shady location.
- (2) Use a cold bath or cold towel to bring down the body temperature. Massage the victim in the cold water bath. Towels have to be changed frequently. Both measures will bring down the body temperature gradually until it is below 38°C.
- (3) The body intravenous injection of some medications also shows good results.

## 2. Heat collapse:

The heart beat and blood flow will increase rapidly under heat. Therefore, the cardiovascular system is over-loaded and results in cardiovascular failure which is the main factor which causes heat collapse. Heat collapse will be triggered by the change of posture when the cardiovascular system is over-loaded. Therefore, the internal body temperature usually is not very high, but the circulatory failure, such as weak and fast pulse and drop of the cardiac output and cardiac

output/min. is very significant. Abnormal perspiration is another diagnostic manifestation. Patients first suffer headache, dizziness, palpitation, nausea, vomiting, paleness, cold perspiration. If no emergency treatment is taken, the patient will soon suffer collapse, with fainting accompanied by dilated pupils, vague consciousness. These are the indications of severe condition. One emergency treatment is to move the patient to a shady place, loosen the clothes, and place ammonia under patient's nose to wake up the patient. The general supportive treatment should also be taken. If the emergency treatment is taken in time, patients will not suffer after effects. It should be pointed out here that there is no basic difference between the over-heating and heat collapse, the only difference is just the individual difference.

### 3. Heat cramp:

Muscle cramp is one of the characteristics. The intolerable pain suffered during cramp is the diagnostic criterion. Cramp usually occurs at the extremities, and is due to the loss of body salt during excessive perspiration. In this case, the ion concentration in the plasma will drop to 90 mN/(normal value is 96-105 mN/l). As an emergency treatment, move the patient to a shady location, and intravenously inject the 500-1000 ml of physiological saline immediately. The patient will usually fully recover, but the muscles will still feel sore even after a few days.

### 4. Sunstroke

It rarely occurs during air and space travel, but occasionally happens in an extremely hot environment. The main cause of sunstroke is the overexposure of the head to strong sunlight. The early-stage symptoms are dizziness, headache, buzzing in the ears, discomfort over the whole body, nausea, vomiting, which may develop into severe symptoms, like cramp

and the loss of consciousness. The diagnostic manifestations are reasonable internal body temperature, continuous perspiration, and the symptoms of the central nervous system. The emergency treatments are:

- (1) Move patient to shady location.
- (2) Immediately cover patient's forehead with a cold towel to drop the body temperature.
- (3) Apply ice bag on the patient's forehead or cool down the whole body with cold water.

Damage can be caused to the central nervous system if emergency treatment is not taken in time.

## II. Adaptation to Heat

It is well known that people will get adapted to the hot environment if they reside or work in such an environment for a long period of time. The adapted persons have higher heat endurance and retain normal working ability under the hot environment.

### A. The physiological change during the heat adaptation.

After the individual adapts to heat, a series of physiological responses to heat are changed, which indicates the compensatory function of body temperature regulation. The actual changes are described as follows:

1. Perspiration rate, heart beat and internal body temperature.

The most significant physiological change after adaptation is increased perspiration rate. The increase of heart beat and rectal temperature will gradually slow down after the adaptation to heat develops. These changes are more significant during exercise, especially the increase of the internal body temperature and the pulse rate. This indicates that equilibrium

is reached between heat production and dissipation. The heat loss through radiation and convection is reduced in the extremely hot environment, therefore, the heat loss has to be compensated for by the vaporization of sweat. If this still cannot balance out the heat storage completely, the metabolic rate will be gradually reduced.

## 2. Skin temperature and peripheral blood flow.

The increase of the skin temperature of individuals who have adapted to heat is less significant than that of unadapted persons. Therefore, the difference between the rectal temperature and the skin temperature is reduced. One important reason why the skin temperature does not fluctuate greater after adaptation is that the peripheral arteriole dilates relatively slowly and the veins constrict to enhance the blood flow back to the heart which further improves the systemic circulation. Its effect is to force body heat to the body surface, and inhibit the conduction of heat from the surface towards the center of the body.

The change of cardiovascular function occurs in the first few days of the adaptation. This is the most significant physiological characteristic during the early stage of adaptation to heat. The increase of cardiac output and the drop of blood pressure will also benefit the blood circulation when the heart beat is relatively slow. This will prevent the heart from overworking, but will, on the other hand, accelerate the conduction of heat from the center of the body towards the surface.

## 3. The change of metabolism

The basal metabolic rate will drop after the adaptation develops. For example, if a male from subtropical area lives in tropical climate for a long period of time, the basal meta-

abolic rate will drop from  $39.7 \text{ Kcal/m}^2\text{.hr}$  to  $31 \text{ Kcal/m}^2\text{.hr}$ . It has been suggested that the drop of the basal metabolic rate results from the relaxation of the straited muscle, especially while lying down to rest. However, this still remains as a controversial subject.

The increase in the metabolic rate during exercise is also less significant after adaptation. The metabolic rate usually starts to decrease gradually several weeks after adaptation. The decreased metabolic rate implies that consumption and heat production are more efficient. Since the requirement for niacin is doubled with exercise in hot areas, people suspect that efficient metabolism may be related to some vitamins. What the actual situation is remains unknown.

#### 4. The composition change of blood and urine.

The concentration of sodium and potassium in the urine decreases after adaptation, which means the retention of sodium is increased. The concentration of hemoglobin and erythrocytes also increases. The results of isotope experiments indicate that plasma volume, total body water volume, and extracellular space increase in the first 5 days of adaptation, and gradually drops back to normal after 5-17 days.

The characteristics of adaptation to heat can be summarized as follows:

- (1) Individuals can adapt to heat completely in 4-7 days.
- (2) Individuals can adapt to heat to a certain degree in few hours of exposure to heat.
- (3) Physical training and good physical condition will benefit adaptation.
- (4) Inadequate water and salt intake will impair the development of adaptation.

(5) The adaptation can last from one to several weeks even after the environmental temperature is switched back to normal.

The following four criteria have been suggested to be used as indicators of developed adaptation to heat.

(1) While exercising in extremely hot weather, the skin temperature and the pulse rate of adapted are lower than those of unadapted subjects.

(2) When changing posture in hot environment, the cardiovascular system is more stable in adapted subjects.

(3) While exercising in hot environment, the perspiration rate increases more for adapted persons.

(4) The same amount of exercise will consume less energy in adapted subjects in the hot environment.

B. Inadaptability to high temperature.

Although individuals can improve heat endurance through adaptation training, the adaptation to heat has its limits. For the majority of the population, the upper limit of heat adaptation is 49°C (dry bulb tem.). However, 6% of the population can never adapt to the hot environment completely, and these will suffer a series of inadaptability symptoms. This is the so-called "heat inadaptability" or "heat feebleness". The symptoms can be classified into 3 categories:

1. Unstable-autonomic-nerve type

The most significant change appears to be the function of the cardiovascular system. The heart beat increases from 72 to 90-110 beats/min and systolic pressure increases by 10-20 mm Hg. The change of diastolic pressure is less significant.

The experiment of posture change indicates that the response of the cardiovascular system is more drastic, the general endurance degenerates, and loss of weight, insomnia, sympathetic-nerve type tremors also occur.

2. Water-and-salt-imbalance type:

After water loss through perspiration reaches 2.5-3.2 Kg, individuals will suffer fatigue, drowsiness, and even cramps. These patients should be supplied with a sufficient amount of water and salt, and usually will recover after several hours of rest.

3. Visual-symptom type:

(1) The vision degenerates: The individuals with normal vision will see crooked images, and those who wear glasses may need a new pair.

(2) Healthy, young people will find that they are losing their regulatory mechanism of vision; therefore, they may have problems in prolonged reading and precision work.

(3) The early stages of presbyopia are aggravated rapidly. It should be pointed out that the symptoms in each category may overlap and the classification is just based on the major symptoms.

C. How to build up the adaptation to heat.

There is no best way to speed up heat adaptation. Here, we can only provide some experimental results for reference.

(1) Heat adaptation training should be performed in hotter environments. If the environmental temperature for training is not high enough, the result usually turns out to be unsat-

isfacotry. During training, the internal body temperature must be kept at a higher level.

(2) Adequate exercise during training will benefit the development of adaptation. The intensity of exercise should be lower than the maximum physical strength, but higher than the minimum physical strength.

(3) The duration of training, training temperature and the amount of exercise should gradually increase as adaptation progresses. All these items should not exceed the subjective tolerable limit or the physiological endurance.

(4) Training under dry and hot environments shows much better results than that under wet, hot conditions. If the humidity is too high, heat adaptation may never develop.

(5) The increased intake of vit-B complex and vitamin C seems to benefit the development of heat adaptation because these nutrients have certain favorable effects on the regulation of metabolism, especially water, salt, and carboyhdrate metabolism.

(6) Using exercise alone to keep a higher internal body temperature will also improve heat adaptation, but its effect is still not as good as a hot training environment.

The data in Table 4-18 and 4-19 can be used as reference.

The following factors have significant effects on heat adaptation:

(1) Heat adaptation develops faster for those who have adapted to heat before.



(2) Males adapt to heat faster than females.

(3) Heat adaptation will start to disappear gradually several days after the stoppage of heat exposure or training, and disappear completely in several weeks. The disappearance of heat adaptation tends to be faster in the winter than in the summer.

It should also be pointed out that heat adaptation may hinder the development of cold adaptation. Their mechanisms are contradictory, but their functions are complementary. Therefore, heat and cold adaptation training can take place at the same time.

TABLE 4-18 Duration of exercise during the development of heat adaptation

reasonably hot			extremely hot		
desert(temp. < 41°C)			desert (temp. > 41 C)		
forest(temp. < 30°C)			forest (temp. > 30 C)		
duration of exercise (hrs.)			duration of exercise (hrs.)		
	AM	PM		AM	PM
1st day	1	1	1st day	1	1
2nd day	1.5	1.5	2nd day	1.5	1.5
3rd day	2	2	3rd day	2	2
4th day	3	3	4th day	2.5	2.5
5th day	routine work		5th day	3	3
			6th day	routine work	

TABLE 4-19 The water requirement<sup>1</sup> in a hot environment  
(Kg/person/day)

Intensity of Exercise	Example	desert (temp. <41°C) forest (temp. <30°C)	desert (temp. >41°C) forest (temp. >30°C)
mild	cooking, office work	0.7	1.1
intermediate	marching on level ground, operation of the tank	0.8	1.2
strenuous	long march- ing, digging	1.0	1.4

<sup>1</sup>It is better to add 1% salt to the drinking water.

### III. Preventions

The most efficient way for preventing heat damage to the human body is to prevent the cabin temperature of planes and space ships to rise too high. In designing and manufacturing the planes and space ships, the cabin temperature must be kept under the tolerable limit and as comfortable (to passengers and crews) as possible.

Adaptation is one way to protect the human body from damage caused by heat. However, there is a limit for heat adaptation. For extremely hot environment, we have to rely on protective equipment and measures.

Among the protective equipment, the protective outfit is the first one to be considered. The protective suit usually combines the design of flying and astronaut's suit. All the

protective measures, including the protective suit, are described below:

A. Protective suit

There are several kinds of protective suits, described as follows:

1. Protection against skin burns: (including gloves, helmets and boots)

This kind of suit, made of low-heat-conductivity and low-heat-absorption material, possesses the fire-resistant and insulation characteristics. The outer 2 layers are usually made of fire-resistant material, and inner one is made of heat-insulation material. The fire-resistant material can stop the heat conduction, and the heat-insulation material can protect the skin against burning. There should be a reasonable gap (4-5 mm is the best distance) between these two materials.

The helmet can be made of fiber glass. In order to retain normal vision, the front side of the helmet has to be made of transparent plastic material. Since the plastic is flammable, it has to be plated with a thin metal layer to increase its heat-resistance.

The protective suit is always covered with a layer of aluminum on the surface to reflect the radiation heat, which will improve one's endurance to heat exposure. However, the aluminum layer will also inhibit the heat loss (by radiation) from the body. Therefore, the coating of aluminum on the surface is not necessarily beneficial if the protective suit has to be used for a long period, but it is definitely helpful if the suit is used for a short period.

## 2. Cover-all cooling suit

There are two kinds: (1) air-cooled suit: Cool air is circulated inside the suit, which will force the hot air to move out of the suit more rapidly. (2) water-cooled suit: There is a small waterpipe system inside the suit which can remove heat on the skin surface while the cool water is flowing.

The air-cooled suit is very effective for increasing endurance to high temperature. With this kind of suit (air temp.:  $7^{\circ}\text{C}$ ; air flow rate:  $27 \text{ m}^2/\text{min}$ . inside the suit), perspiration and respiration are decreased greatly, the fluctuation of body temperature is also reduced and the heat endurance is greatly improved. Therefore, one can remain comfortable in a  $71^{\circ}\text{C}$  environment, if the skin temperature can be kept in the comfortable temperature range (around  $32.5^{\circ}\text{C}$ ). With the aid of the air-cooled suit, one can tolerate the cabin temperature of  $125^{\circ}\text{C}$  for 4 hours. The comparison between the air-cooled suit and other similar protective suits is shown in Figure 4-29 and 4-30. As shown in Figure 4-29, it seems that the working hours can be extended if the air-cooled suit is used.

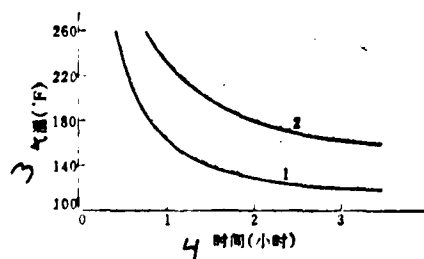


Figure 4-29. The relationship between protective suits and heat under the condition that working efficiency is not affected. Key: 1. with optimal normal clothing, 2. with air-cooled suit, 3. temp ( $^{\circ}\text{F}$ ), 4. time(hr).

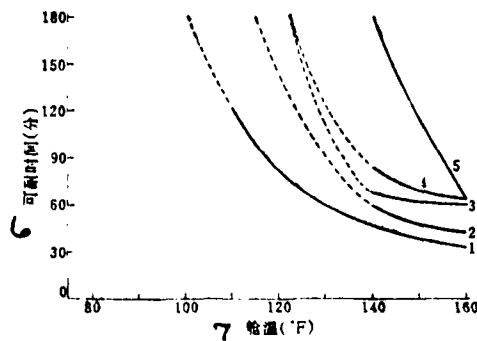


Figure 4-30. The effect of ventilation in the protective suit on the heat endurance.

1. with thin, non-ventilated protective suit.
2. with thick, non-ventilated protective suit.
3. with thick, semi-ventilated protective suit.
4. with thick, ventilated protective suit.
5. with thin, ventilated protective suit.
6. tolerable duration (min).
7. cabin temp. (°F).

The air-cooled suit should be comfortable, light, durable, and easy to use with the flying or astronaut's suit. In order to get the best result, the flow of cool air should be kept as close as possible to the body surface.

In the water-cooled suit, air is replaced by water as coolant. The heat conductivity of water is ten times that of air. Therefore, the heat dissipation efficiency in the water-cooled suit is much better than that of the air-cooled suit. However, the water-cooled suit also has its disadvantages. One of the disadvantages is that the contact area between the body surface and the water pipe is very limited, therefore, the temperature of the water has to be kept very low in order to get better results, which, on the other hand, will cause discomfort to the contacted surface area. A thin layer of cotton can be placed between the human body and pipe system to overcome the discomfort that may be caused by the cold water. Experimental results prove this arrangement to be very satisfactory.

The other disadvantage of the water-cooled suit is that cold water will cause the blood vessels at the contacted area to constrict, and result in hematoma. Therefore, the air-cooled suit is still recommended under the conditions that exercise is not too strenuous and the environmental temperature is not very high. When the environmental temperature is high and exercise is very strenuous, it is better to use the water-cooled suit.

Since the heat loss varies among different parts of the body, the distribution of water pipes should also be different at different parts. A distribution of the pipelines is suggested in Table 4-20.

TABLE 4-20 A suggested distribution of the water pipe system.

Parts of the body	Distribution of the water pipe(local pipelines / pipelines over the whole body) (%)
head and neck	25
upper arm	15
forearm	5
trunk	30
thigh	17
calf	8
total	100

### 3. Local cooling

Heat regulation varies among different parts of the body under hot conditions. The muscle which is involved in exercise will usually show higher temperature. Therefore, when one puts on the water-cooled suit, he may feel cool as a over-all feeling, but feel hot at some special locations. The cooling

of the head and the skeletal muscles plays an important role in maintaining comfort. However, the cooling of the skeletal muscle will not improve its efficiency, and, may even impair the efficiency of delicate operations if it is cooled down too much. We all agree that the surface areas which have high perspiration rate, dense blood vessel distribution and less muscle attachment should be cooled down more, but the skeletal muscle should be maintained at a certain temperature level in order to retain normal working efficiency.

The cooling of head and lower-level central nervous system (e.g., spine) can significantly improve one's heat endurance. For example, the cooling of the head and spine 1-1 1/2 minutes before reaching the tolerable limit (to heat) can improve one's working efficiency, mental status and heat endurance. In other words, keeping the central nervous system in a cooler condition has significant effect on the improvement of heat endurance, and, of course, a more significant effect on the efficiency of mental work.

#### B. Other preventive measures against high temperature

##### 1. Cooling of the cabin

The methods involved are very similar to the methods of bringing down the room temperature. For equipment and procedures, one can consult engineering technical books.

##### 2. Cooling of the cabin wall

This is one way of cooling down the cabin temperature. For supersonic jets and space ships, the excessive heat usually comes from the cabin wall, therefore, the cooling of the cabin wall should be discussed more extensively.

The friction and the compression of the air will produce a great amount of heat during the take-off and return of the space ship. Special measures should be taken to dissipate this heat. Otherwise, not only the crews cannot tolerate this heat, but also the space ship may be burned out (during the returning trip). The following measures are suggested:

- (1) Carefully select the appropriate kinetic coefficients of the space ship to minimize the temperature increase of the cabin wall.
- (2) Use effective heat dissipation devices or insulation to keep the surface or cabin temperature as low as possible.
- (3) Through good insulation, minimize heat conduction from the surface to the cabin.

The high surface temperature of the space ship is usually attributed to solar radiation. The selection of the right color coating on the surface will affect the cabin wall temperature.

### 3. Increase the ventilation

Use of a ventilation system (e.g., fan) can increase the air flow and improve the heat dissipation. However, the ventilation may have a negative effect when the environmental temperature is much higher than the body temperature.

4. Heat which does not exceed the tolerable and safe limit is usually safe. To set up a safety limit is just a protective measure. It has been reported in a foreign country that: In 1952, an army of 10,000 soldiers were stationed at a tropical area and the average incidence of heat stroke was 39.5 per summer. A safety rule was set up on 1956. When the



WBGT temperature reached 26.7°C, the newcomers had to take protective measures. When the WBGT temperature reached 29.4°C, unadapted individuals had to cut down physical activities. When the WBGT temperature reached 31.1°C, all the soldiers who had been there less than 10 weeks had to stop physical training completely. While WBGT was between 31.1 and 32.2°C, even the adapted soldiers had to limit their physical training to a maximum of 6 hours per day. Physical training had to be cut down more if WBGT was above 32.2°C. Following this rule, the incidence of heat stroke dropped to 0.52-4.7 cases/10,000 soldiers. Another group of paratroopers were transferred from the temperate zone to tropical area. They took the training the day after their arrival. The incidence rate of the heat-stroke was 10% on the 1st day of the training, 29% on the second day of the training. Later, all the newcomers were forced to take the first day off, and the incidence rate of heat stroke dropped to 1%.

5. Pre-cooling before exposure to heat can greatly improve the endurance

Soaking in 15°C water for 90 minutes can decrease the internal body temperature by 1°C. This pre-cooling measure before exposure to heat (71°C) can postpone the occurrence of collapse for 114 minutes. If the rectal temperature drops 1.1°C due to pre-soaking before heat exposure, then the tolerable duration can be extended from 60 minutes to 120 minutes. The air-cooled suit and the water-cooled suit can replace water soaking as the pre-cooling method.

6. Sufficient supply of water will improve the heat-endurance

When the environmental temperature is between 48 and 50°C, the water storage volume in the human body is about 3 liters

which is sufficient to survival for 2-2.5 days. If the water storage capacity is increased 10 fold, the survival time can be doubled under the best conditions. The increase of water intake will increase the vaporization heat loss of the body, which will improve the heat endurance. When the body is in need of water, it is better to drink a small amount of water constantly than take in a large quantity of water once in a while. However, the effect of water on the improvement of endurance has its limit because an overload of heat can make one reject water. It is better to add 0.1% of salt to all drinking water or 0.5% salt to half of the daily drinking water.

7. The composition of the inhaled air can affect the endurance.

Inhalation of pure oxygen and dry, cold air or increases of the  $\text{CO}_2$  content in the inhaled air will improve the heat endurance. However, these factors cannot play a significant role in improving the endurance, and can only serve as supplemental measures.

8. Regular physical activity can improve the endurance

Improved physical strength and a good health condition will also improve the heat endurance. However, swimming has a negative effect on improving endurance.

## Chapter 18. The Effect of Cold and the Cold Prevention

### I. The Physiological Effects and Damage of Cold

#### A. General Physiological Responses to Cold

In a cold environment, the maintenance of the internal body temperature in a stable range mainly depends on the function of the temperature regulatory system. Therefore, the rectal temperature can be maintained at  $37.2^{\circ}\text{C}$  even though the skin temperature drops to  $30^{\circ}\text{C}$ . The rectal temperature will not show any change until the skin temperature drops below  $21^{\circ}\text{C}$ . In other words, the rectal temperature will stay constant if the environmental temperature is above  $9.3^{\circ}\text{C}$ . The internal body temperature will drop only when the environmental temperature drops below  $9.3^{\circ}\text{C}$ . The drop of the internal body temperature indicates that the temperature regulatory system cannot satisfactorily compensate for the heat loss any more, and the tolerable limit is reached after this point. The major physiological responses to low temperature are as follows:

#### 1. Response of the peripheral blood vessels:

The peripheral blood vessels constrict in a cold environment, which minimizes the heat loss through the peripheral circulation and maintains a constant internal body temperature. The maximum effect of this physiological response can only be equivalent to that of an 0.1-0.8 insulation unit. On the other hand, a mild, short cold stimulus may cause the peripheral blood vessels to dilate in order to recover skin temperature. This is another kind of compensatory mechanism. Actually, the dilation response of

the peripheral blood vessels will also occur while the environmental temperature is very low, especially in windy, extremely cold weather. When the peripheral tissues are cooled down to a certain degree, the peripheral blood vessels will lose their response to the constriction impulse from the sympathetic nerve. Therefore, the blood vessels may dilate either spontaneously or passively. In a cold environment, physical activities will also cause a certain degree of dilation of the peripheral blood vessels.

## 2. Trembling

Trembling can generate heat. The strongest trembling can produce 350-400 Kcal of heat per hour. However, a spontaneous trembling can only stop or minimize the drop in body temperature, and cannot raise the body temperature because it cannot compensate for the heat loss completely. Naked and inactive individuals will start to tremble in the first half hour under 10°C. If naked subjects are exposed to 4°C (wind speed: 16 Km/Hr), the trembling will begin in a few minutes.

Trembling usually starts locally, first at the upper and lower palates. Trembling will then spread from the face to limbs, breathing muscles, and eventually over the whole body if the body temperature keeps on dropping. The trembling usually occurs intermittently. The period becomes shorter and the duration of the tremor lengthens while trembling is spreading over the whole body. The nerve impulse caused by intense trembling is irregular and strong which causes an uncomfortable feeling when the message is sent to the cerebrum. Trembling and stiffness of hands together can increase the difficulty of manual operations. Trembling resulted from the imbalance between activation and inhibition mechanism of the cerebellum.

### 3. Increased metabolic rate

The metabolic rate will be increased in a cold environment. It is well accepted that tremor and exercise will increase the metabolic rate. But how about the direct effect of cold on the metabolic rate? Yes. The cold environment can increase the metabolic rate through a series of functions of the nerve and body fluids. Cold weather will also increase the  $O_2$  consumption and the food intake. The effect of a cold environment on the amount of food intake is shown in Table 4-21.

Table 4-21. Food requirements in different cold environments

Daily requirement (Kcal/person day)	Environmental temperature (°C)	Activity
3800(3400) <sup>1</sup>	-18	marching
4000(3600)	-24	marching
4500(4000)	-26	marching
4400(4000)	-26	driving
4200(3800)	-27	driving
3600(3600)	-32	camping outside
3800(3800)	-27	camping outside

### 4. The response of the cardiovascular system

The heart beat usually increases in a cold environment. The cardiac output and the blood pressure also show increasing trends. However, if the rectal temperature drops below 34°C due to an extremely cold environment, the heart

<sup>1</sup> The figure in the parentheses indicates the lowest value.

beat will slow down. When the rectal temperature drops to 30°C, the victim will suffer ventricular fibrillation. When the rectal temperature drops to 27°C, fibrosis of the blood vessels will appear. The blood will become extremely viscous at 20°C rectal temperature, which will impair circulation and cause great danger. The minimum rectal temperature for survival (in clinical cases) is 30°C. People can seldom regain consciousness if the rectal temperature drops to 28°C. One can hardly survive in the presence of viscous blood.

#### 5. The response of breathing

The respiration rate and the pulmonary exchange volume usually increase in a cold environment, which is comparable to the increase of the metabolic rate and heat production. However, in extremely cold weather, and while trembling, one loses control of breathing.

#### 6. Electromyogram (EMG) and electroencephalogram (EEG)

The electroencephalogram (EEG) does not show significant changes in an extremely cold environment. But some people occasionally show a drowsy-type of EEG while awake. By soaking the hands in 10°C water for 15 minutes, the latent period and each stage in the EEG will be shortened. The change of the latent period is due to the inhibition of cerebral function. The changes of the individual stages is due to the direct effects of the cold stimulus on the muscles.

#### 7. The change of the functions of other systems

Staying under 14.5°C for consecutive 2 days will cause

a decrease in the concentration of plasma adrenocorticosterone, tryptophan, tyrosine and the increase uroxanthin content in the urine. The change of blood composition after being exposed to +2 - -5°C for 3 hours (rest, with 1-insulation unit clothes) is shown in Table 4-22. The increase of plasma adrenocorticosterone content is most significant among all the changes, which indicates that the nerve-anterior pituitary gland-adrenal cortex system is significantly affected by a cold environment. This has been proven in animal experiments, but its physiological significance still remains controversial.

Table 4-22. The change of blood composition after cold exposure.

Items	Control (normal temp., rest)	After exposure to cold for 3 hrs.
hemoglobin (g/100 ml)	14.2	15.3
blood volume (as percentage of control)	100	92.3
plasma volume (as percentage of control)	100	87.9
Conc. of serum creatinine (mg/100 ml)	0.99	0.93
Conc. of plasma adrenocorticosterone (mg/100ml)	0.02	13.3

The function of the central nervous system will be severely disturbed if the temperature drops to an extremely low level. Forgetfulness, disorientation will occur if the rectal temperature drops below  $34^{\circ}\text{C}$ . Below  $30^{\circ}\text{C}$ , an individual will suffer sharp pain over the whole body and unconsciousness. Below  $27^{\circ}\text{C}$ , an individual will lose the ability of voluntary movement, pupil reflex, tendon reflex and skin reflex, which indicates a mortal risk. When extreme cold causes the internal body temperature to drop to the level of unconsciousness, all the physiological mechanisms will slow down, and approach a full stop. The metabolic rate at  $30^{\circ}\text{C}$  rectal temperature is only half of the normal value. The decrease of the pulmonary exchange volume is even more drastic than the metabolic rate drop. The impairment of circulation is also significant. When the rectal temperature drops below  $30\text{--}32^{\circ}\text{C}$ , the cardiac function will be impaired.

#### B. Local Frostbite and Injury Caused by Cold

The most common effect of low temperature is local frostbite and injury caused by cold. Local frostbite usually occurs after exposure to the environmental temperature below  $0^{\circ}\text{C}$  for a long period of time. The hands and feet suffer frostbite more easily, while the humidity is high. Frostbite may occur on the face in 12 seconds if the individual is exposed to  $-73^{\circ}\text{C}$ . It takes a little longer for frostbite to appear at  $-23^{\circ}\text{C}$ .

There are two kinds of local frostbites:

(1) wet-type: Small blisters appear on the skin surface. Fluid comes out of the blisters. Bleeding under the nails, which is similar to the damage caused by pressure.



(2) dry-type: Limbs are frozen like ice cubes. The skin feels like a piece of glass. The clinical development of frostbite can be classified into 3 stages:

- (1) the occurrence of rashes: Patients can fully recover.
- (2) the occurrence of blisters: The after-effects depend on the treatment.
- (3) the occurrence of gangrene: Tissues are dead, usually occurring on nose tip, ear lobes and extremity ends.

Most of the frostbite cases appear from 5 to 8°C. The tissues which have suffered frostbites before are more susceptible to it. O<sub>2</sub> shortage and cold body are supplementary factors for frostbite.

Under extremely cold conditions, the skin will stick to a metal surface if they contact each other. This is one characteristic of injury caused by cold, which may occur during space travel. If the environmental temperature is below -20°C, any skin surface with slight moisture on it will adhere to the metal, especially oxidized aluminum and iron. It is more difficult for skin to adhere to shiny metal surface, such as copper and silver. The skin can hardly adhere to a metal surface which is covered by snow, dust, rust or design patterns.

The mechanism of tissue damage due to cold deserves more study. There are two hypotheses about the mechanism:

- (1) extreme cold causes the extracellular fluid to freeze; therefore, the water inside the cell diffuses out of the cell and results in a dehydrated cell. The development of frostbite is rashes + blisters + water in a blister, resulting in + tissue gangrene. This seems to be a valid hypothesis.

(2) Circulatory impairment is a decisive factor. It can be observed that the blood in the capillaries will stop flowing after freezing for 3 minutes, and the thrombus will gradually form large blood vessels. This hypothesis assumes that gangrene is caused in the following sequence: cold distribution of the vessel epithelium → serum diffusion → coagulation of platelet and blood cells → blockage of the blood vessels → O<sub>2</sub> shortage in the tissue → tissue gangrene.

The purpose of the emergency treatment is to regain body temperature. If the rashes and blisters have already appeared, it is not necessary to reheat the body. The procedures for recovering body temperature are: raise the temperature to 30°C in two hours, then rapidly to 40°C, and then immerse the victim in a warm bath. If necessary, medication can be used. Some antibiotics, diuretics and tonics can be administered depending on the overall symptoms and local condition.

First degree freezing injury can mend without any treatment. For second degree freezing injury (e.g. blisters on palms and feet), the blisters should be broken and antibiotics ointment should be applied to the blister area. The treatment of third degree freezing injury, including closed-treatment, CO<sub>2</sub> shower, compressed O<sub>2</sub> treatment, and surgical treatment, must depend on the condition of the patient.

There are two kinds of frozen-stiffness: chronic type, caused by prolonged exposure to cold (but not extreme cold) and the acute type, caused by sudden exposure to cold and rapid freezing. The chronic-type victim will experience a series of physiological changes during the early stages of cold exposure, and then suffer the pathological symptoms.

At this time, the body temperature cannot be maintained constant and starts to drop rapidly, and stiffness will gradually appear. For the acute-type patient, the body temperature drops rapidly which gives no time for the body to defend itself or compensate for the drastic change. Therefore, in a very short period, the body will lose its control of the body temperature, and victims will soon suffer severe symptoms. If the patient cannot regain consciousness right away, he may lose his life. Even though the patients can recover, they usually suffer from aftereffects.

#### C. The Effect of Cold on the Flying Ability

The effect of cold on sensation and flying ability is shown in Table 4-23.

The effect on the sense of touch appears first at 15-20°C. This may result from the impairment of the sensory and message-delivering mechanism of the sensors on the skin. When the skin temperature drops to 15-15.6°C, the efficiency of delicate hand-work (e.g. knitting) and tracking operations is not affected until the skin temperature drops below +5°C. The effect of cold on the hearing and time-consciousness is non-significant. The effect on conditioned reflexes and unconditioned reflexes usually will not show unless severe symptoms start to appear.

#### D. Factors which Affect the Physiological Responses to Cold

The physiological responses to cold are affected by many factors, such as clothing, subjective mobility, duration of exposure, area of exposure, exposed parts,

Table 4-23. The Effect of Cold on Working Efficiency

Temperature		Identifying Ability by Sense of Touch	Supervision	Tube Assembling	Typewriting & Knitting
30	skin temp.	slightly degenerate			
25	environ- mental temp.	significantly degenerate	✓		
22	in the water	significantly degenerate		✓	
15-15.6	skin temp.				✓
10	environ- mental temp.				
4.4	environ- mental temp.				
-1.1	wind speed (16-48Km/hr)				
-45.5	with protec- tive suit				

Table 4-23 (Continued)

Temp.	Grasping	Tracing Ability	Visual Response	Writing and Assembling of a Cogwheel	Hearing Response
30					
25					
22					
15-15.6					
10	✓				
4.4		✓			
-1.1			✓		
-45.5					✓

"V" indicates detrimental effect.

health condition, adaptation, race, age, sex, season, wind speed and humidity, etc. It makes no sense to discuss all these factors in detail. The readers only have to remember that all these factors are correlated and complementary. All the factors should be considered as a whole, not individually.

## II. Adaptation to Cold

### A. Basic Concepts

One can adapt to a cold environment after a long exposure. This is called the cold adaptation. Adaptation to cold can develop either naturally or by training. After the adaptation, the endurance of cold can be increased significantly, and the physiological response to cold will be reduced.

Adaptation to cold does not occur suddenly; it takes a series of physiological processes to develop it. During the 1st-2nd week, there is significant improvement in adaptation. One can almost adapt to cold completely in the 4th-6th week of exposure. Physical training will improve the development of adaptation.

One can train for both cold and heat adaptation at the same time. These two adaptation trainings can be applied alternatively (e.g. one day for cold adaptation and the next day for heat adaptation). This alternative training can give better results than separate training.

## B. The Mechanism of Cold Adaptation

What is the mechanism of cold adaptation? The adaptation of pearl divers to cold sea water can serve as a good example in explaining this mechanism.

A study was done on the "sea ladies", females who dive to the depths of the sea to collect pearls in Korea and Japan. They can dive in winter and function well even though their body temperature is only 5°C. The main mechanism of this cold adaptation is to decrease the heat conduction on the "body surface", and increase the metabolic rate (not from exercise or tremor) under cold conditions (in cold water). The so-called "body surface" refers to the area which is between the internal tissues and the skin surface. This is to differentiate from the core of the body. Cold can reduce the volume of the "core" area and increase that of the "surface" area. The expansion of the "surface" area mainly occurs on the extremities, not the trunk and head. Due to the reduction of the "core" area, the effective surface area for heat conduction is reduced. In a cold environment, the peripheral blood vessels of the "sea lady" will constrict drastically, and the heat conduction of the body "surface" will decrease accordingly, which results in a decrease of heat loss. For the "sea lady", the heat conduction of the "body surface" can drop by 20-90%, much higher than for the average person.

It has been suspected that the increase of the hypodermic adipose of the "sea lady" is another reason for the decrease of heat conduction. However, the study shows that the adipose tissue is not any thicker in the "sea lady" than in average Korean women or obese persons. Although the result contradicts this hypothesis, the correlation

between the adipose tissue and heat conduction still cannot be ignored. The combining effect of the increased adipose tissue and the decreased peripheral blood flow can reduce the heat conduction 5 fold. The insulation of tissues other than the adipose tissue also plays an important role in the reduction of heat conduction. Although the "sea lady" has the same amount of adipose as the average Korean woman, their tissue insulation is much better than that of the average woman. The water content in the tissues may contribute to the difference of the tissue insulation value, because the heat conductivity coefficient is  $0.36-0.52 \text{ Kcal/m}^2 \cdot \text{hr. } ^\circ\text{C}$  for water, but  $0.16 \text{ Kcal/m}^2 \cdot \text{hr. } ^\circ\text{C}$  for adipose.

The higher metabolic rate of the "sea lady" is another important factor which contributes to their strong endurance of cold. Their food intake reflects their metabolic rate. The calorie intake of the "sea lady" is 1000 Kcal more per day than that of a non-diver woman. The "sea ladies" seldom tremble in cold water which is supposed to help prevent heat loss in water. They can work in  $29^\circ\text{C}$  water for 3 hours and will not tremble, even though their body temperature drops to  $1^\circ\text{C}$ . Only trained long-distance swimmers have this ability. In other words, for the "sea lady" the metabolic mechanism of cold adaptation is attributed to the increased metabolic rate, not the heat increase due to trembling or exercise while they are working. This indicates that the "sea ladies" already developed a series of nerve-endocrine compensatory mechanisms: The cold stimulates the nerve and, through the nerve-anterior pituitary gland-adrenal cortex-adrenal medulla-thyroid function, there is an increase in the metabolic rate, and appetite (especially for meat), and a decrease in heat loss from the skin.

Protein has a special effect on heat production. The "sea ladies" are fond of fish and the Eskimos are fond of animal meat, which all indicate a natural defense mechanism against the cold.

It can be concluded that the improved endurance of cold after immersion in cold water is mainly attributed to the increased insulation value of the body surface, decreased heat conduction and increased metabolic rate.

For the further understanding of the mechanism of the cold adaptation, another experiment can be introduced here: Three amateur divers put on rubber diver's suits (6-mm thickness) and rubber shoes (4-mm thickness), and were immersed in water (30 cm under the water surface) for 30 minutes without moving. The environmental temperature is 3.8-5.5°C; wind chill factor is 2-3 degree. The same routine is repeated every day for 45 consecutive days. The results show that there are 3 stages of cold adaptation: (1) first stage, unadapted stage: Cold triggers a series of physiological responses, especially the increase of the metabolic rate to compensate for the heat loss. (2) second stage: The heat loss and the decrease of the internal body temperature cannot be compensated for by the increase of the metabolic rate. No trembling occurs yet. It is believed that the brain has already adapted to the cold. (3) third stage, close to complete adaptation: During this stage, the internal body temperature is more stable, and the metabolic rate will increase slightly. These are the results of the enhanced constriction of the peripheral blood vessels and the accumulation of the adipose tissue under the skin, which decreases the heat conduction through the blood towards the body surface and minimizes the heat loss to prevent the internal body temperature from dropping.



How long can the cold adaptation last? It depends on the degree of the adaptation. For the previous case (30 min. training for 45 days), the adaptation ability disappears completely 17 days after the training stops. However, the adaptation ability can last for a half a year if it was developed under natural conditions and the duration of cold exposure was about one month.

Cold adaptation shows negative effects on the decompression and O<sub>2</sub> shortage training. It will affect the developed heat adaptation, but it will not cause the heat adaptation to disappear completely.

### III. Prevention

If the environmental temperature drops below 15-5°C, simple preventive measures should be taken to prevent frostbite on the extremity ends. When the temperature drops below -6.7 - -12.1°C, preventive measures for the whole body should be taken. All the preventive measures, including clothing, will be discussed as follows:

#### 1. Clothing

Comfortable clothing should have 1 insulation unit at 21°C, 2 insulation units at 12°C, 3 insulation units at 3.3°C, 8 units at -6.7°C, and 11 units at -12°C. Clothing of 2.5 mm thickness is equivalent to 3 insulation units. An army heavy coat can reach 4.8 insulation units maximum. Clothes with higher insulation units will be too bulky and heavy to wear and lose their practical value. The insulation values for comfortable clothing during different outdoor activities are shown in Table 4-24. The insulation of the clothes is closely associated with the

dryness of the clothes, wind speed, and the compactness of the clothes. When the clothes are wet and compressed, and the wind speed is high, the insulation effect of the clothes will drop significantly. The insulation of dry socks and shoes is double that of wet ones. The insulation value of the different materials can also be expressed in terms of the heat conductivity value. The faster the heat conducts, the worse the insulation will be.

From the physiological point of view, the temperatures of various parts of the body are correlated. Maintenance of the trunk temperature can significantly improve one's endurance to the cold. Since the extremities easily suffer freezing injury, they should also be kept warm. Double layers of socks are better than a single layer of the same thickness.

Table 4-24 Insulation requirement of clothes during different outdoor activities (to feel comfortable).

Temp.	Seated, rest	Walking on Level Ground		
		Slowly	Average	Fast
21	1.5	0.7	0.4	0.3
10	3.1	1.5	0.9	0.7
- 1.1	4.7	2.3	1.5	1.1
-17.6	7.2	3.5	2.3	1.7

## 2. Heating inside the clothes

In an extremely cold environment, we cannot just count on regular clothing to keep us warm enough. For example, in extremely cold water, we need a 2.5 mm thick diver's suit to keep our body temperature constant. But this causes a great deal of inconvenience and still cannot avoid the freezing injury on the toes and fingers. On the North Pole, in order to keep the hands warm, during 6 hours of rest, one has to wear gloves as thick as 1/6 of the body height. If the duration of rest is prolonged without limit, the gloves have to be as thick as 1/3 of body height. This is impossible to do. Therefore, under extremely cold conditions, the clothes have to be heated. The clothes can be heated either by air or water, and the gloves and boots can be heated by batteries. The structure of the air-heated suit is shown in Fig. 4-31. One economic and efficient way is to put on PolarGuard-type (foamy synthetic material which can insulate very well) clothes. Boots and gloves are heated by batteries.

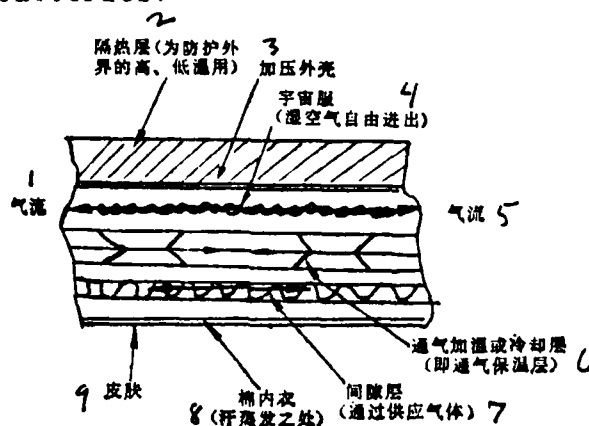


Fig. 4-31 Schematic diagram of the air-heated protective suit.

1- air flow; 2- insulation layer (to insulate from the high, low temp. in the environment); 3- compressed surface; 4- astronaut's suit (wet air can go in and out freely); 5- air flow; 6- air heating or cooling layer (the layer for air flow); 7- interval-layer for air-passage; 8- cotton underwear (where vaporization occurs); 9- skin

## 3. Indoor Heating

Heating devices include furnace, electric heater, etc.

#### 4. Physical activity

Strenuous physical activities can increase heat production by 1400 Kcal/hr. which is 20 times the normal metabolic rate (70 Kcal/hr). Therefore, the physical activities can serve as a defense against cold. However, the duration of the physical activities has to be limited. In a  $-20^{\circ}\text{C}$  environment, one will not feel comfortably warm without any exercise even with clothes on. However, exercising under water does not have the same effect because exercise in the water will increase the heat loss and further decrease the body temperature. Only those who are used to the training in cold water can use swimming to retain body temperature a few hours. For the majority of people, exercise should be minimized in cold water.

#### 5. Pre-heating of the body

Pre-heating before being exposed to the cold environment can improve cold endurance. However, heating by warm water immediately after the victim is rescued from cold water may cause the internal body temperature to drop under  $30^{\circ}\text{C}$ . Therefore, gradually heating is necessary in this case.

#### 6. Inhalation of oxygen and medication

Inhalation of pure oxygen can improve the efficiency of manual operations in a  $5^{\circ} \pm 1^{\circ}\text{C}$  environment. Some heat-production stimulants show the same effect, but they are not recommended for use on the victims.

In addition, the complementary effects of nutrition, selection, and physical training have long been well known.

## Part V The Biological Effect of Radiation

### Introduction

Radiation is an important environmental factor in space /207  
travel. Radiation is electromagnetic waves. Photon energy  
decreases with increased wave length. Therefore, its biolo-  
gical effects decrease with an increase of wavelength. For  
radiation of wavelength less than  $1800\text{\AA}$ <sup>(1)</sup>, the energy of  
each photon can be higher than  $3\text{ eV}$ <sup>(2)</sup>. This can have not only  
a thermal effect, but also an ionization effect. It is harm-  
ful to the human body. At the present time, it is very diffi-  
cult to prevent this type of high energy radiation and it is  
one of the major obstacles to space travelling. Radiation  
at a wavelength between  $1800\text{-}4000\text{\AA}$  is called ultra-violet.  
The energy per photon is between  $7\text{-}3.1\text{ eV}$ . Its effect on  
the human body is mostly thermal. Radiation with the wave-  
length between  $3800\text{-}7800\text{\AA}$  is normal visible light. Its effect  
on the human body is simply vision. Extremely strong visible  
light, such as a laser, can do much harm to people. Radiation  
with a wavelength between  $7800\text{-}1.25 \times 10^6\text{\AA}$  is called infrared.  
The energy per photon is between  $1.5\text{-}0.008\text{ eV}$ . Its effect on  
the human body is purely thermal. Radiation with a wavelength  
between  $1.25 \times 10^6\text{\AA}\text{-}769\text{cm}$  is called microwave. It is used in  
radar, microwave communications and heating. Its photon  
energy is between  $4 \times 10^{-4}\text{-}1.2 \times 10^6\text{ eV}$ . Its effect on the human  
body is mostly thermal. Radiation with longer wavelengths is  
used in TV and radio. Its effect on the human body is minimum  
and is not important to space travel. It will not be discussed  
here.

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<sup>1</sup> $\text{\AA} = 10^{-7}\text{ mm}$

<sup>2</sup> $1\text{ eV} = 1.6018 \times 10^{-12}\text{ erg}$      $1\text{ MeV} = 1.6018 \times 10^{-6}\text{ erg}$

$1\text{ BeV} = 10^9\text{ eV} = 1.6018 \times 10^{-3}\text{ erg} = 3.83 \times 10^{-11}\text{ cal}$

$1\text{ eV}$  is the energy an electron acquires as it travels through  
an electric potential of 1 volt.

The objective of this part is to discuss the radiation effect on the human body and how to prevent it. For the convenience of discussion, we will include the biological effects of the atmospheric ions also.

## Chapter 19 Ionizing Radiation and its Biological Effects

### I. Introduction

#### A. Some basic concepts of ionizing radiation

Any atom is composed of the nucleus (neutron and proton) and the electrons. The total no. of the neutrons and the protons in the nucleus is called the atomic weight (A) of this atom. The number of protons is called its atomic number (Z). The atoms with the same atomic number, but different atomic weight, are called "isotopes". The atomic number is always written on the lower left corner of the element, and the atomic weight is always on the upper right corner of the element. For example,  ${}_8^{18}\text{O}$  is an isotope of the oxygen atom. If the structure of the atom changes, energy will either be absorbed or emitted. The emission of the particles during this process is called radiation. If the radiation can cause the ionization<sup>1</sup> of the material, it is called the ionizing radiation. Following are the different types of radiation:

##### 1. Photon radiation

A photon is an electromagnetic wave. X-rays and  $\gamma$ -rays possess the characteristics of ionizing radiation. The wavelength of x-rays is longer than that of the  $\gamma$ -ray. X-rays are caused by the bombardment of outside particles, which force the electrons in the inner orbit to emit. As the electrons in the outer orbit fill up the vacant space in the inner orbit, energy is emitted and x-rays are formed. The wavelength of  $\gamma$ -rays is shorter. It is created as the nucleus structure changes and the extra energy is radiated.

1. Ionization: the formation of ions from atoms.

## 2. $\beta$ -rays

$\beta$ -rays are caused by the change of a neutron or proton in the nucleus. When the neutron changes into a proton, it will emit an electron ( $\beta^-$ ). When the proton changes into a neutron, it will emit the positively-charged particle ( $\beta^+$ ). Both are called  $\beta$ -rays, but the former kind is more commonly seen.

## 3. $\alpha$ -rays

$\alpha$ -particles includes 2 neutrons and 2 protons. Only an element with atomic number greater than 83 can emit this kind of radiation.

## 4. Neutron radiation

Neutron radiation usually occurs when the nucleus is split. According to the energy level, the neutron can be classified as a slow neutron (energy less than 1 KeV), intermediate neutron (energy between 1-500 KeV), and fast neutron (energy between 0.5-10 MeV). The neutron is not charged.

Various types of radiation cause different changes in the atoms depending on the charges, the mass and the energy levels. Some radiation can only affect the electrons to cause ionization. Some can affect the nucleus and cause a nuclear reaction. Since the final result of the nuclear reactions is still ionization, therefore, both kinds of radiation together are called ionizing radiation.

## B. The units of ionizing radiation

The number of atoms undergoing the transformation per unit time indicates the intensity of the radiation source. One



of the units for radiation intensity of the Curie (C or Cu). One Curie is equal to the number of  $\gamma$ -particles emitted by 1 gm of radium per second.  $1C = 3.7 \times 10^{10}$  particles/sec. Another unit is the Rutherford (Ru).  $1Ru = 10^6$   $\gamma$ -particles/sec. and  $1C = 3.7 \times 10^4$  Ru.

The intensity of radiation is often expressed in terms of roentgen(r). One r is defined as the quantity of incident photons (x-rays or  $\gamma$ -rays) that will produce one electrostatic unit of electricity in 1 cm<sup>3</sup> of dry air at 0°C, 1 atm. In other words, 1r = 1 cm<sup>3</sup> air to produce  $2.083 \times 10^9$  ion pairs = 1g air to produce  $1.61 \times 10^{12}$  ion pairs = 1 cm<sup>3</sup> air to absorb  $6.77 \times 10^{10}$  eV = 1 g air to absorb  $5.2 \times 10^{13}$  eV = 1g air to absorb 83 erg. Every gram of biological tissue will absorb 93 erg of energy per unit of r- of x-ray incidence.

When the same intensity of radiation passes through higher density material, it produces more ionization. In order to have equal ionization quantities on different materials, another unit, rep<sup>1</sup>, is introduced. One rep is the radiation intensity that can cause 83 erg of energy absorption per cm<sup>3</sup> of material. For biological applications, 1 rep is the radiation intensity that produces 93 erg absorption per gram of tissues. In 1954, the International Radiation Unit Committee defined the unit "rad", which is the energy absorbed from ionizing radiation equal to 100 ergs per gram of radiated material. One rad approximately equals one rep.

Since different radiations have different biological effects, other units, such as "reb" and "rem", are also used in biology. One "rem" is the amount of ionizing radiation

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<sup>1</sup>1 repL 1 rep = 1 biological tissue intensity protected by 1g/cm<sup>2</sup> lead plate.

required to produce the same biological effect as one roentgen of high-penetrating x-rays. Since different animal and different tissues have different sensitivity to different radiation, it is impossible to have an exact definition for "reb" and "rem". Roughly speaking, "rem" is related to "r" and "rep", as shown in Table 5-1.

TABLE 5-1 Relative radiation units for different ionizing radiations (approximation)

radiation	r	rep	rem
x-ray, $\gamma$ -ray	1	1	1
$\beta$ particles	1	1	1
protons (<10MeV)	1	1	1
protons	1	1	10
protons (10-100 MeV)	1	1	4
protons (>100MeV)	1	1	10 ~ 1
hot neutrons	1	1	5
fast neutrons	1	1	4 ~ 10
slow neutrons	1	1	4
$\alpha$ particles	1	1	10
disintegrated particles	1	1	27
electrons (<30 KeV)	1	1	1.7

## II. Radiation environment in space travel

### A. Radiation in the Milky Way

Two types of ionizing radiations may be encountered during space travel: the natural cosmic radiation and the artificial radiation. Cosmic radiation includes: (1) Milky Way radiation (2) radiation from the sun. (3) Radiation from the galaxy (the radiation around the earth). Table 5-2 shows

the general radiation. In addition to the primary radiation mentioned above, secondary radiation may be generated when the particles interact with the atmosphere, the space ship, and the human body.

TABLE 5-2 Radiation in the universe

Radiation source	Space range	reb	Remarks
milkyway radiation	600Km above the earth	0.007	dosage in the central tissue
	inter-galaxy	0.13	max. solar activity
		0.26	max. solar activity
	moon surface	0.13	max. solar activity
earth radiation	600Km above the earth	0.12	proton intensity on the surface of organisms.
		2.0	electron intensity on the surface of organisms.
	1500Km elevation	reaches 5	proton dosage in central tissue
		reaches 3000	electron dosage on the surface of organisms.
	1500-1800Km elevation	reaches 100	proton intensity in the central tissues
		reaches 50000	electron intensity on the surface of organisms
date of solar explosion			
1956,2,23		280	
1959, 5,10	outside the earth's magnetic field	5400	intensity on the surface of the organisms after the explosion
1960,3,9		2.5	
1960,11,12		1000	

The Milky Way cosmic rays come from the high-energy charged particles in all the directions of the Milky Way. It includes cosmic rays from outside the Milky Way. Cosmic-ray particles are mostly atomic nuclei: 85% (79-93%) are protons, 14% (6.3-20%) are  $\alpha$ -particles (he-nucleus), and 1% (0.7-2%) are heavy nucleus. Each particle contains  $0.1 \times 10^9$  eV- $10^{19}$  eV of energy (ave:  $3.5 \times 10^9$  eV).

The average number of particles involved in the Milky Way cosmic radiation is around 4-4.5 particles/cm<sup>2</sup>.sec during the years which the sun is inactive and 1.8-2.5 particles/cm<sup>2</sup>.sec during the active years. The dosage of Milky Way cosmic radiation can reach 100 Reb/year in the interstellar space, but will drop to 50 reb/year during the years of maximum solar activity. The average intensity of cosmic-rays in interstellar space is 60-70 reb/year. The average intensity of cosmic rays which are close to the earth's surface is 5-10 rad/year during maximum solar activity, and 10-20 rad/year during minimum solar activity, and the typical value is 10 rad/year.

The primary Milky Way cosmic-rays usually interfere with the magnetic field of the earth, and are absorbed by the atmosphere around the earth. Therefore, it can rarely reach 12Km above the earth's surface. The atmosphere layers around the earth are equivalent to a protective layer with a thickness of 1000g/cm<sup>2</sup>, and its protective effect is equivalent to a 10-m thick layer of water and 0.9m thick layer of lead. After the primary cosmic-rays enter the atmosphere and interacts with the atoms in the atmosphere (nuclear reaction), secondary cosmic-rays are produced. Due to the effect of the atmosphere on the formation of the secondary cosmic-rays and its effect on the absorption of primary cosmic-rays, the cosmic-ray intensity in the upper layers of the atmosphere, will increase as the altitude decreases.

The intensity of cosmic-rays reaches its maximum value at 15-24Km and drops gradually after this altitude. Roughly, cosmic-ray intensity at sea level is about  $1.8 \times 10^{-2}$  particles/cm<sup>2</sup>.sec, which is lower than in the upper layer of the atmosphere (2 particles/cm<sup>2</sup>.sec.cubic angular degree).

The particles of the Milky Way cosmic-ray possess a very high energy and have a high penetration ability. Therefore, protection must be provided. The radiation intensity due to the protection of space ship's surface of 2 g/cm<sup>2</sup>, does not drop significantly in the space ship. No significant change can be observed in cosmic-ray intensity even though the density of the shell increases to 10-15 g/cm<sup>2</sup>. The cosmic rays will drop off 1.5-2 times only after the thickness of the ship surface is increased to 70-100 g/cm<sup>2</sup>. Due to the effect of secondary cosmic-rays, damage caused by the ionization will tend to increase in the "core" part of the body (compared with skin surface). However, if the density of the shell is increased to a certain level, the intensity absorbed by the human body will decrease in regions closer to the center of the body.

#### B. Solar cosmic radiation

Solar radiation includes two types: (1) solar cosmic-rays which comes from the solar explosion or the solar wind (the low-energy particles ejected from the sun). (2) Solar magnetic radiation, including light and heat radiation.

Solar cosmic-ray causes more danger of ionizing radiation in space travel. "Solar explosion" means the sudden release of a great deal of energy from a small area on the solar surface. One typical explosion can reach its maximum power within 1 minute. A short flash will appear at the climax, and the energy will level off after this point. A large quantity

of radiation particles will be emitted during this process, which is composed of solar cosmic-rays. There is a close correlation between the frequency of the solar explosion and sun spot activity. Explosions will occur more frequently at the times of increased sun spot activity. The average frequency of explosion in a month is used as an indication of solar activity. One cycle varies from 7 to 14 years (average 11 years). The number of sun spots can reach 50-200 during the years of maximum solar activity. The explosion frequency can reach 100 times per year during the years that the sun is rather active, and will drop to 1-3 times/year during inactive years. The average frequency is about 1-16 times/year.

Solar explosions are usually accompanied by the ejection of the high-energy particles among which the protons are in the majority. Therefore, solar explosion incidence is also called solar proton incidence. According to the energy level of the protons, solar explosion can be classified into 3 stages:

- (1) high-energy explosion incidence: If the energy of protons is higher than  $20-50 \times 10^9 \text{ eV}$ , the duration is longer than 10 hrs, and frequency is 1 time/4-5 years, then, the explosion is classified as B-type explosion. The integral energy spectrum can be expressed as  $(1+E)^{-6}$  (E is the particle energy,  $10^9 \text{ eV}$ ). The solar explosion which occurred on Feb. 23, 1956 belongs to this type.
- (2) Intermediate-energy explosion incidence: The energy of protons is between one to several  $10^9 \text{ eV}$ . The frequency can be 2-4 times as high during years when the sun is active.
- (3) Low-energy explosion incidence: If the energy of protons is  $30 \times 10^6 - 400 \times 10^6 \text{ eV}$ , frequency is 10-12 times, then, it is classified as an A-type explosion. Its integral energy spectrum is

close to  $E^{-4}$ , and the proton intensity can reach  $10^8$  protons/cm. The intensity of A-type explosions with a protection of  $0.1 \text{ g/cm}^2$ ,  $1 \text{ g/cm}^2$  and  $10 \text{ g/cm}^2$  lead shell are, respectively, 230, 85, and 20 rads. The intensity for the same kind of protection, are, respectively, 110, 80, and 35 rads for B-type explosions intensities. All these did not take the secondary radiation into account. The intensity of the secondary radiation is about 5-10% of that of the primary radiation. For a shielding of  $10 \text{ g/cm}^2$  in thickness, the proton dosage of the secondary radiation can be equivalent to that of primary radiation for an A-type explosion. The various types of the solar explosions, which may be encountered during a 7-day space travel, is shown in Table 5-3.

TABLE 5-3 The incidence of the solar explosions during 7-day space travel

Various types of explosions	Average Frequency <sup>1</sup> (in one year)	The probability of encountering explosions during 7-day space travel (%)
low-energy particles, high intensity (min. type)	9	16
low-energy particles, extremely high intensity (intermediate type)	3	5.8
high-energy particles, high intensity (max. type)	0.25	0.3

<sup>1</sup>The intermediate-intensity and high-intensity solar explosions, which may affect the unprotected astronauts detrimentally, occur, at least, 3 times a year and 100 times at most.

A large-scale solar explosion can last for several hours, and a small-scale explosion can last for several days. The particles ejected from the explosion usually can reach the earth's vicinity in one hour, first at the polar areas. Its intensity can reach to the maximum value in 10 minutes to several hours.

The particles ejected in the solar explosion are composed of protons (about 90%),  $\alpha$ -particles and some  $Z > 6$  heavy atoms (less than 0.5%), including C, N, O. The solar explosion is sometimes accompanied by high-energy electrons. The energy level of the ejected high-energy electrons is  $40-150 \times 10^3$  eV. Its instantaneous intensity can reach several thousand times that of normal Milky Way cosmic rays. Its low energy-level contributes to its low penetrating ability. Therefore, it is easy to counteract, and less alarming.

The maximum instantaneous intensity of solar proton incidence can exceed the normal Milky Way radiation by 3-4 times. With no protection, the tissue dose of protons outside the earth's magnetic field can reach to several rads, but this rarely occurs. The radiation dose which can penetrate through the space ship during two typical solar high-energy proton incidences is shown in Figure 5-10. The radiation energy spectrum, collected for one typical solar proton event and which can penetrate into body in different depths, is shown in Figure 5-20. Even under the protection of the thick materials, the radiation does caused by a solar explosion can still reach intolerable levels. Therefore, the surface of the space ship has to be at least,  $3 \text{ g/cm}^2$  in thickness in order to protect against the lowest-level solar explosion.



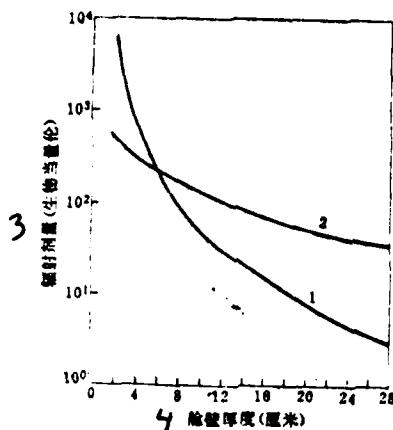


Figure 5-1. The radiation dose that the cabin may be exposed to during a solar explosion.

1. the solar explosion on May 10, 1959.
2. the solar explosion on Feb. 23, 1956.
3. radiation dose (reb),
4. thickness of the cabin wall (cm).

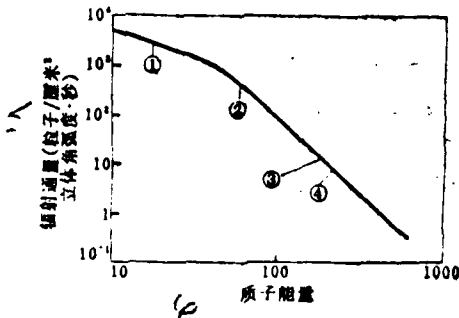


Figure 5-2. Proton spectrum of the solar explosion (Nov. 15, 1960) and its penetrating ability through the human body. (The four figures indicate the penetrating ability of the protons at different energy levels).

1. through the skin , 2. into the bone marrow and the digestive tract, 3. through half of the body's width, 4. through the whole body, 5. radiation intensity (particles/cm<sup>2</sup>. cubic angular degree.sec), 6. proton/energy (10<sup>12</sup> eV).

In addition to the solar explosion, the sun continually ejects low-energy ions, which is called the "solar wind". Although the solar wind occurs continuously, its low-energy makes it less harmful than other radiations.

The sun continually sends out the electromagnetic radiation. Its radiation spectrum and the absorption spectrum by  $O_3$ ,  $H_2O$ , and  $CO_2$  are shown in Figure 5-3.

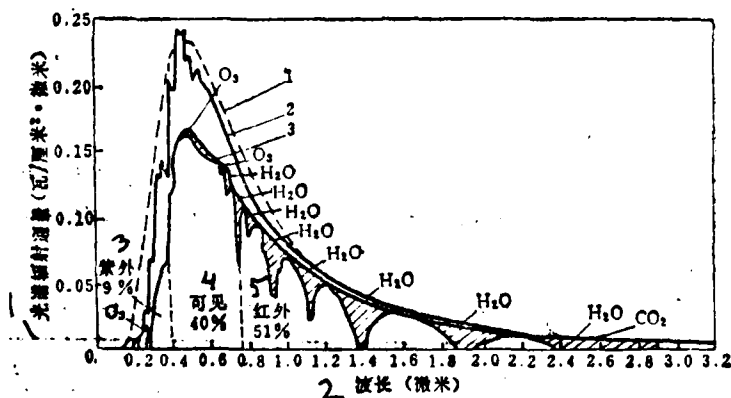


Figure 5-3. Solar radiation spectrum and its absorption spectra by  $O_3$ ,  $H_2O$ , and  $CO_2$  in the atmosphere.

dotted line 1 - energy curve of the 6000°K sun spot.

solid line 2 - solar radiation curve outside the earth's atmosphere.

solid line 3 - solar radiation curve at sea level.

(The percentages above the x-axis indicate the energy level of each as a percentage of the total solar radiation).

1. spectrum radiation intensity ( $\text{watt}/\text{cm}^2 \cdot \mu\text{m}$ ), 2. wavelength ( $\mu\text{m}$ ), 3. ultraviolet 0.05-9%, 4. visible 40%, 5. ultrared 51%.

### C. The terrestrial radiation zones

There are two radiation zones around the earth. One is called the inner radiation zone, and the other is called the

outer radiation zone. The intensity of the radiation is higher in these two zones. The location and the particle distribution of these two zones are shown in Figure 5-4. The figures at 0° latitude, such as 1/1.0, 1/2.0, etc, indicate the distance away from the earth: 1/2.0 means 2r (r; earth's radius) away from the earth; 1/3.0 means 3r away from the earth, etc. The proton zone is to the left of the earth and the electron zone is to the right of the earth. The number of black dots in Figure 5-4 indicates the density of protons (or electrons).

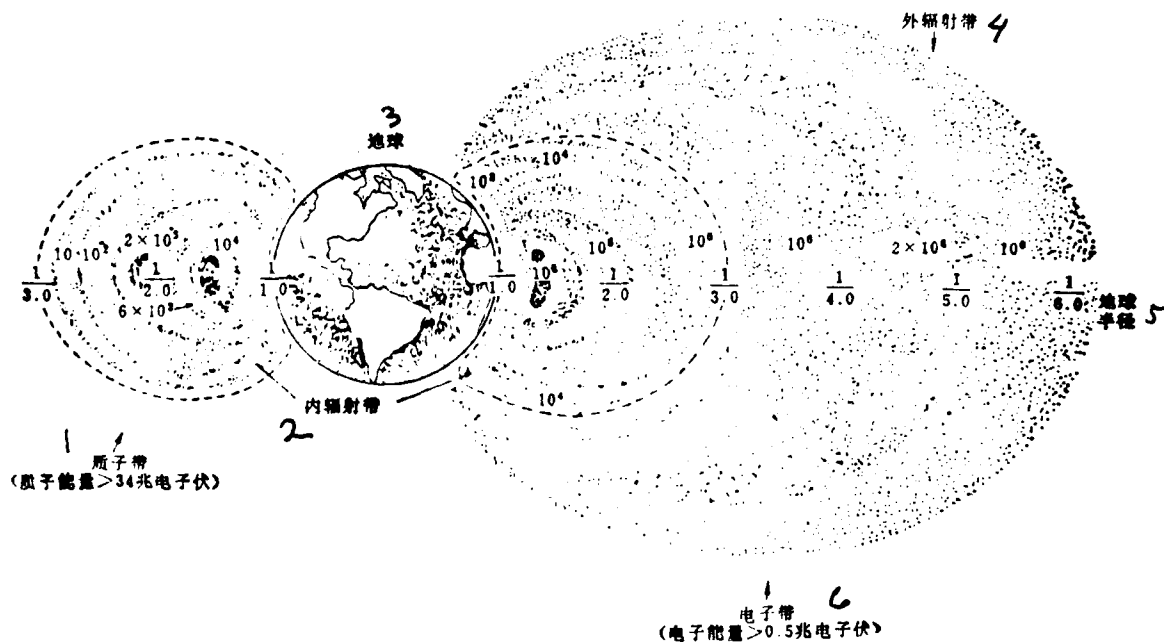


Figure 5-4. Proton and the electron distribution in the radiation zones around the earth.  
 1. proton zone (proton energy  $> 34 \times 10^{12}$  eV) 2, inner radiation zone, 3. earth, 4. outer-radiation zone, 5. earth's radius, 6. electron zone (electron energy  $> 0.5 \times 10^{12}$  eV).

The radiation zone closer to the earth is called the inner radiation zone (I-radiation zone). The lower limit of the I-radiation zone is at 350-1500Km altitude, which is different for the western and eastern hemisphere. For example, the lower limit at 45°W is at 500-600Km altitude and that at 45°E is at 1500Km. The upper limit of the I-radiation zone is at 4500-10,000Km, and the highest-intensity zone is around 3000-4000Km. The high-energy particles are more densely distributed closer to the earth's surface, contrary to the distribution of low-energy particles. Their distribution are shown in Table 5-4. The inner radiation zone is distributed between 40°-45° latitude.

TABLE 5-4 The radiation intensity and the center (highest-intensity zone) of the inner radiation zone.

Types of particles	Energy range (10 <sup>6</sup> eV)	Max. intensity particles/cm <sup>2</sup> . sec)	Altitude of the center area (Km)
Protons	>4	>10 <sup>8</sup>	about 5000
	>15	>10 <sup>5</sup>	about 4000
	>34	>2.0 x 10 <sup>4</sup>	about 3500
	>50	>4.0 x 10 <sup>8</sup>	about 3000
Electron	>0.5	>10 <sup>8</sup>	about 3000

Outside the inner radiation zone, there is an outer radiation zone (II-radiation zone). Its lower limit is usually at 10-30Km (avg. 15,000Km), but, at the latitudes of 55°-70°, the lower limit can drop to 300Km, even 200Km. Therefore, any orbit near the earth's surface with an inclination angle greater than 50° will pass through the outer radiation zone. The upper limit of the outer radiation zone is at 50,000-70,000Km, and its center is 15,000-25,000Km above the earth's

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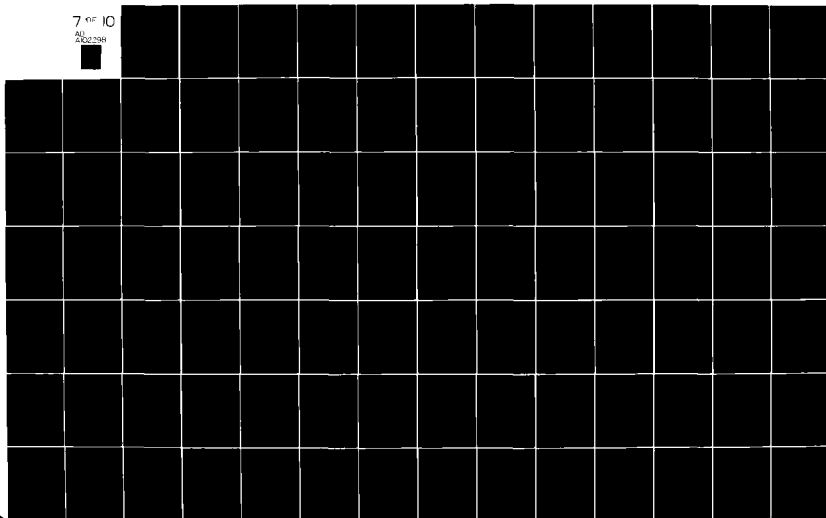
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surface. The intensity peaks at 17000Km and 23000Km, as shown in Table 5-5. The outer radiation zone is located between 55° and 70° latitude.

TABLE 5-5. The maximum intensity and the center of the outer radiation zone.

Types of particles	Energy range ( $10^6$ eV)	Max. intensity particles/cm <sup>2</sup> . sec)	Elevation of the center area (Km)
Electron	>0.045	$2 \times 10^8$	about 2100
	>0.5	$2 \times 10^7$	
	>100	<10	
Proton	>30	<10	

It has been suggested that there is another radiation zone, outside the outer radiation zone, the III-radiation zone. It is located 50,000-60,000 Km above the earth's center. It is composed of low-energy particles (especially the electrons). Its intensity is  $10^8$  particles/cm<sup>2</sup>.sec. cubic angular degree, and will not cause any danger to space travel. Whether there is a IV-radiation zone outside the III-radiation zone still remains doubtful. All these radiation zones (I, II, III, IV-radiation zones) are called the terrestrial radiation zones. They are distributed symmetrically along the 0° latitude, and form an angle of 11°-15° with the equator.

Among all the terrestrial radiation zones, the inner zone is the strongest in radiation intensity, which is mainly composed of electrons and high-energy protons (energy can reach  $10-100 \times 10^{12}$  eV). The radiation dosage of the inner radiation zone, is 5-10/hr for electron and x-ray, and 100r/hr. for protons. Without any protection, the intensity received in the center of the inner radiation zone will be 20 rem/hr. The energy of the electron in the inner zone ranges from 100,000

to 500,000 eV. The average intensity received under a 1 g/cm-thick protective device is 0.1 r/hr. The intensity can reach a maximum of 120 rads/hr in the inner radiation zone if protection of 2 g/cm<sup>2</sup> is provided. The penetration is weaker for the electrons in the outer radiation zone, therefore, under the 5 g/cm<sup>2</sup> shielding, it will not cause mortality. If an aluminum plate is used for shielding, it only has to be 4.5mm thick. The penetrating ability is stronger for the protons in the inner radiation zone. Therefore, the intensity can still reach to 5 reb/hr. even under the 1 g/cm<sup>2</sup> shielding. Sixty percent of the radiation of 3000 particles/cm<sup>2</sup>.sec can penetrate through the 2.5 g/cm<sup>2</sup> protective layer. The proton intensity can still penetrate the 5 g/cm<sup>2</sup> shielding. A lead plate of 10 g/cm<sup>2</sup> is required to protect against the radiation of 100x10<sup>12</sup> eV protons. The intensity can reach a maximum of 8-10 rads/hr. in the inner radiation zone even under the 5-10 g/cm<sup>2</sup> shielding. It takes about 15 minutes to fly across the inner radiation zone. The total intensity can reach 2-3 rads even under the 10 g/cm<sup>2</sup>-thick shielding which can be threatening. Therefore, it is better to fly out from the polar areas to avoid the radiation zone. Under various thickness of lead shieldings, the tissue absorption intensity of the protons in the inner radiation zone is shown in Table 5-6.

TABLE 5-6 The tissue absorption dosage<sup>1</sup> of the protons in the inner radiation zone under different lead shielding

Thickness of lead surface	1 g/cm <sup>2</sup>		7.5 g/cm <sup>2</sup>		20 g/cm <sup>2</sup>	
	mrads/sec	reb/sec	mrads/sec	mrem/sec	mrads/sec	mreb/sec
unit of the dosage	0.88	1.11	0.56	0.68	0.31	0.38
average tissue	2.81	3.26	1.09	1.33	0.50	0.57
skin surface local tissue	4.42	5.6	1.71	2.12	0.72	0.84

<sup>1</sup>At the center of the inner-radiation zone, the intensity shielding can reach 8-10 rads/hr. under the 5-108/cm<sup>2</sup>-thick and  $3 \times 10^4$  rads/hr. during solar explosions. The relative biological effects for these two situations are 0.5 and 0.6-1.4, respectively

The outer radiation zone is mainly composed of electrons and low-energy particles. These particles possess lower penetration ability, and are easy to protect against. The average intensity is 200 rad/hr. under no protection, and it will drop rapidly under any protection. In the outer radiation zone, the radiation of  $10^4$  r/hr. will drop to 200 r/hr under a shielding 1 g/cm<sup>2</sup> in thickness. If the thickness of the shielding increases to 4 g/cm<sup>2</sup>, the radiation will keep on dropping to 2 r/hr. It takes a space ship about 2 hours to pass through the outer radiation zone. The total dosage under the 1 g/cm<sup>2</sup> shielding is only 0.2-0.3r. Therefore, this does not cause too much risk.

During solar explosions, the radiation intensity will



temporarily increase in the inner and outer radiation zones. The radiation intensity will be enhanced 5-fold in the upper layer of the earth's atmosphere, 2-3 fold in the outer radiation zone, 2 fold in the inner radiation zone, and several times under extreme situations. The inner and outer radiation zones are the result of capture of the cosmic-ray particles by the magnetic field of the earth.

D. Other sources of ionizing radiation

1. Other radiation sources and zones in aerospace

In addition to the sun, many other planets send out radiation. Any planet with the magnetic field around it is surrounded by the radiation zone. For example, a radiation zone has been found around Jupiter. Its energy level is about 10 times that of the terrestrial radiation zone and its intensity is 200 times that of the terrestrial zone. However, other radiation sources cannot be explored extensively due to technical difficulty.

2. Radiation pollution from nuclear equipment in the space ship.

If nuclear energy or nuclear weapons are used in the space ship, radiation pollution will become an important subject. Since they are not used yet, we will not discuss this issue.

3. Artificial radiation caused by the nuclear explosion tests.

The high-speed electrons ejected from the nuclear explosion tests in the atmosphere can be captured by the magnetic field to form an artificial radiation zone. Its intensity can exceed that of the natural radiation zone by several degrees.

In 1958, an artificial radiation zone of 150Km in width appeared at 450-500Km altitude after 3 nuclear explosion tests. Its electron energy can be several million eV, and the radiation lasts for 1 month. Under a  $4.5 \text{ g/cm}^2$ -thick shielding, the nuclear explosion test on July 9, 1962, still has an intensity of 3r/hr. after 2 months. The nuclear explosion tests done by various countries already form an artificial radiation zone around the earth. Its center is located at 3000-6000 Km, and the maximum radiation intensity is  $2 \times 10^9 \text{ electrons/cm}^2 \cdot \text{sec}$ . Its radiation intensity is  $10^7 \text{ electrons/cm}^2 \cdot \text{sec}$  at 2500Km above the equator, and  $10^5 \text{ electrons/cm}^2 \cdot \text{sec}$  at 1500Km altitude. The dose received by the space ship while it travels through the artificial radiation zone is 2-3 reb under  $1-2 \text{ g/cm}^2$ -thick shilding.

#### 4. Secondary radiation

Secondary radiation can be caused by the interaction of the primary radiation particles with the space ship, atmosphere and the human body. It can cause the ionization of the air, production of  $\text{O}_3$ , and the radiation of contaminated food and water. There is a close correlation between the secondary radiation and the thickness of the space ship surface. As shown in Figure 5-5, the radiation intensity inside the cabin will increase in proportion to the thickness of the ship's surface. This is due to the increase of secondary radiation induced by the ship's surface. The primary radiation particles can interact with the body tissues to produce secondary radiation. Therefore, the radiation intensity inside the tissues may be higher than on the skin surface. Sometimes, the dose inside the tissues can be double that on the skin surface, and the local tissue intensity can be 10 times the average tissue intensity.

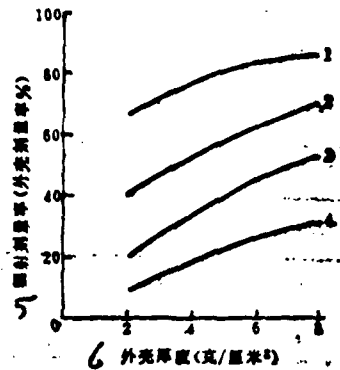


Figure 5-5 Secondary radiation caused by the ship surface  
 1. 2 hours after the solar explosion, 2. 4 hours after the  
 solar explosion, 3. 16 hours after the solar explosion, 4. 48  
 hours after the solar explosion, 5. radiation dosage (on the  
 surface, %), 6. thickness of the ship's surface.

The radiations which may be encountered in space travel  
 are summarized in Table 5-7.

TABLE 5-7. The source and the intensity of the various  
 radiations in space.

Radiation source	Basic Particles	Energy ( $10^{12}$ eV)	Intensity (Particles/cm <sup>2</sup> . sec)	Dosage (rad/hr)
Milky Way cosmis radiation	35% pro- ton	$10^3 \sim 10^{14}$	$2 \sim 4.5$	$5 \times 10^{04}$
solar explo- sion	proton	$10^3 \sim 5 \times 10^4$	$10^3 \sim 10^{10}$	$3 \sim 10^4$
inner radia- tion zone	proton elec- tron	$0.12 \sim 7 \times 10^2$ $0.04 \sim 0.6$	$2 \times 10^4 \sim 10^3$ $2 \times 10^6 \sim 10^8$	100
outer radia- tion zone	proton elec- tron	$0.1 > 7.5$ $0.01 > 5$	$0.1 \sim 10^8$ $10^4 \sim 10^9$	$10^4$

TABLE 5-7 (Continued)

Radiation source	Basic Particles	Energy ( $10^{12}$ eV)	Intensity (Particles/cm <sup>2</sup> . sec)	Dosage (rad/hr)
artificial radiation zone caused by nuclear explosion texts	electron	0.05 >5	$3 \times 10^8$ $3 \times 10^8$	$-90^1, 0^2$
secondary x-ray	x-ray			0.55
nuclear powered equipment	neutron	>0.05	$10^{12}$	$0.47^3$
		>1.0	$6^{12}$ $10^{16}$	117 reb

1. under 2 g/cm<sup>2</sup>-thick lead shielding
2. under 6 g/cm<sup>2</sup>-thick lead shielding
3. the maximum dosage under mercury layer shielding while flying.

### III. The radiation intensity during air and space travel

#### A. Estimation and measurement of the radiation intensity during space travel

There are various estimates of the radiation intensity which may be received during space travel. Since the conditions are different, these estimations can only be used as a reference. (1) The intensity received in different orbits (different elevation, 1/2 different angles) are shown in Table

5-8 and Figure 5-6. The relationship between the detected intensity (at various elevations) and the latitude is shown in Figure 5-7 and Table 5-8.

TABLE 5-8 The radiation intensity on the surface of the space ship in different orbits

elevation				
the radiation intensity on the surface				
angles of the orbit (degree)	0.2 ~ 0.6	1 ~ 1.5	2.5 ~ 3.5	7.5
0	3.2	3.5	9.7	38.1
45	8.1	13.2	24.5	47.2
65	14.5	21.2	32.5	49.6
90	17.4	23.8	34.5	50.2

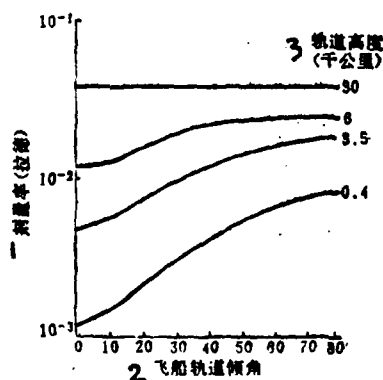


Figure 5.6. The intensity of the Milky Way cosmic-radiation on the ship's surface in different orbits (during the year of min. solar activity).

1. intensity (rad), 2. angles of the orbits, 3. orbit elevation.

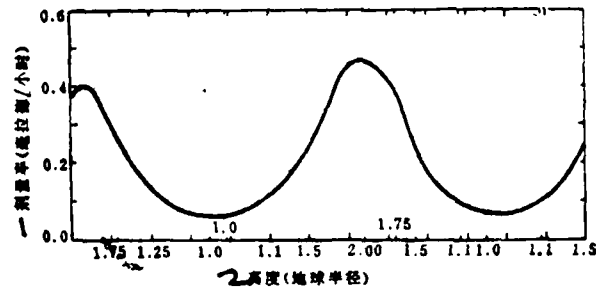


Figure 5-7. The radiation intensity received inside the cabin.  
1. intensity (rad/hr), 2. altitude (earth's radius).

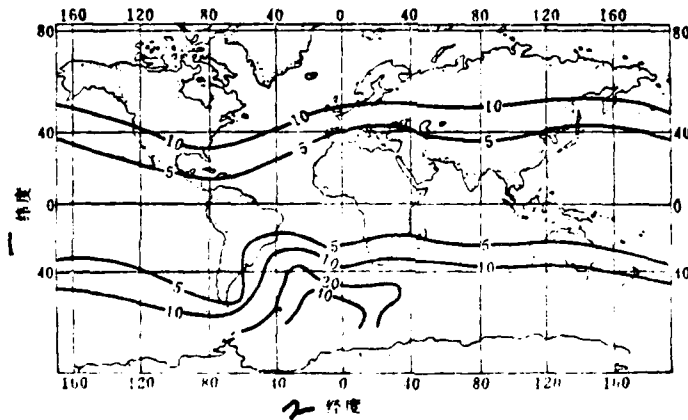


Figure 5-8. The relationship between the geographical location and the radiation intensity received inside the cabin. (Each curve indicates one radiation unit. The figure on the curve is the intensity in rad/day).  
1. latitude, 2. longitude.

(2) The radiation intensity on the space ship while it travels through the terrestrial radiation zones is shown in Figure 5-9a.

(3) The radiation intensity that the space ship will be exposed to during a solar explosion is shown in Figure 5-11, 5-12, and 5-9(b), (c).

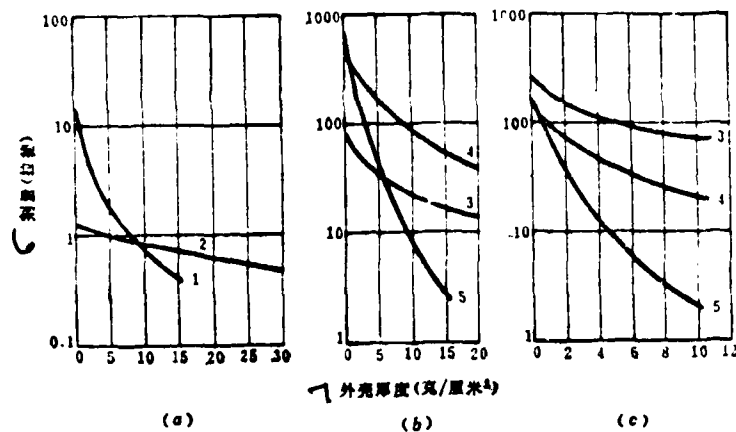


Figure 5-9. The radiation intensity inside the cabin under different shieldings while the space ship travels through the terrestrial radiation zones and during solar explosions.

- a. while the space ship travels through the terrestrial radiation zones.
- b. during the solar explosion (for the space ship in high orbit).
- c. during the solar explosion (for the space ship in the lower orbit).
1. the intensity of the primary proton radiation, 2. the inhibited radiation intensity, 3, 4, 5-3 different solar explosions, 6. intensity (rad), 7. the thickness of the cabin surface.

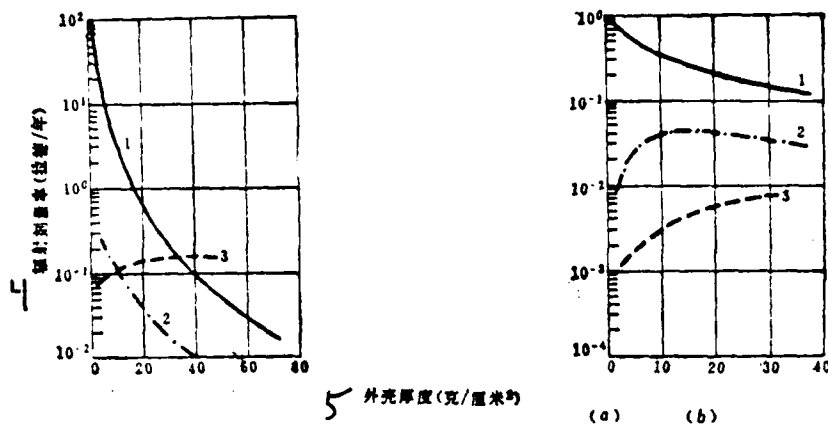


Figure 5-10. The ratio of the primary radiation to secondary radiation during the solar explosion (May 10, 1959).  
 a. the radiation intensity at 23 hours after the explosion.  
 b. the proton intensity in the inner radiation zone.  
 1. primary proton radiation  
 2. secondary proton radiation  
 3. secondary neutron radiation  
 4. radiation intensity (rad/year)  
 5. the thickness of the cabin surface

(4) Using the solar explosion on May 10, 1959, for study, the estimation of the intensity of secondary radiation is shown in figure 5-10. As shown in Figure 5-10, it seems that the secondary radiation intensity increases as the thickness of the ship's surface increases.

Under the most favorable conditions, the space ship travelling on an equational orbit will receive  $7 \times 10^8$  rads of electron intensity and  $2 \times 10^7$  rads proton intensity from the primary cosmic radiation. After the radiation particles pass through the 0.25 mm-thick aluminum surface, the electron intensity drops to  $3 \times 10^8$  rads/year and the proton intensity drops to  $3 \times 10^5$  rads/year, but secondary x-rays of  $3.7 \times 10^4$  rads/year in intensity appear. Therefore, it seems that the astronauts will be exposed to a total radiation intensity of 100 rads/year, which is beyond the safe limit.



From the observations of 18 space travel cases, it can be concluded that, under the shielding of the ship's surface, human beings will be exposed to the average cosmic-radiation intensity of 22 rads/day.

B. The problem of cosmic radiation in supersonic jets

The speed of the supersonic jet (passenger or air force) may be 2 or 3 times that of the sound. It can fly between an altitude of 15-22.5Km, carry 100-300 passengers or 23-27 tons with the range of 3000-4000 nautical miles. The terrestrial radiation zones will not cause any problem to the supersonic jets at the altitude they are flying. However, the effect of the Milky Way cosmic radiation and solar cosmic radiation should not be ignored completely.

The distribution of the Milky Way cosmic radiation, within the altitude range which the supersonic jets are flying, is shown in Figure 5-11. The intensity of the cosmic radiation can reach 15 mr/day at 24 Km, and 6 mr/day at 10.5 Km. The intensity of the Milky Way cosmic radiation can reach to 240 mrem/hr. at 9Km, and 102mrem/hr at 20 Km (about 100-200 times the value at sea level). The experimental (the plane flies above 12,000m for 2 hours and 9 min. -- 9 hrs. 25 min. The total flying time is 4 hrs. 17 min.-- 23 hrs. 45 min.) results indicate that the radiation intensity inside the cabin (tested at the pilot's and passenger's seat) is between 0.1 and 2.5 mrad( ave. 1 mrad). At the same time, the intensity of cosmic radiation on the ground is found to be 0.2-0.3 mrad. Based on the above data, it can be postulated that the crew members in the supersonic jets will receive 0.5-1 rem of the Milky Way cosmic radiation every year. When working in the polar areas, the total intensity can reach 2 rem/year. The safety limit is 5 rem/year for each crew member and 500 mrem

for the passengers. Therefore, it is obvious that normal cosmic radiation intensity will not exceed the safety limit.

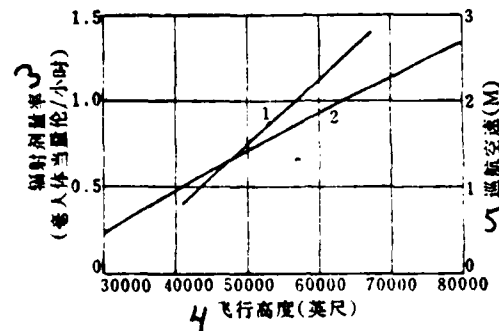


Figure 5-11. The relationship between radiation intensity, flying altitude and cruise speed of supersonic jets.  
1. cruise speed, 2. the radiation intensity of the Milky Way cosmic radiation, 3. radiation intensity (mrem/hr), 4. flying altitude (feet), 5. cruise speed(M).

The cosmic radiation intensity will be greatly increased during a solar explosion. At the regular flying altitude of the supersonic jets, the radiation intensity for a solar proton accident can reach 2-3 rem/hr which already exceeds the safety limit by 20-80%.

For protection against the solar proton accidents, supersonic jet planes can neither be equipped with heavy shielding nor can medication be administered to the crew members. The best way is to stop the flight or return to the ground as soon as the incident is detected. Right now, the incident can be predicted 7 days before it actually happens and only 6% of the predictions prove to be wrong. After the solar explosion, it will take more than 20 minutes for the development from a solar optical change until protons reach the earth's atmosphere. Therefore, by using the solar optical changes to predict the occurrence of solar proton incidents, sufficient time is available to send out the warning. The plane has to lower its altitude at the moment it receives the warning. The

airplane should be equipped with a radiation alarm device which can indicate the radiation intensity in case the predictions cannot be made or delivered on time. When the radiation intensity is lower than 10 mrem/hr, it is safe to fly around. When the radiation intensity is between 10 and 100 rem/hr, the alarm device should send out a signal. If the intensity is above 500 rem/hr, the alarm device should send out a sound warning to remind the pilot to bring the plane down to a safe altitude.

According to the statistics, the solar explosion almost never happens from December to mid-January, and only occurs on small scale between May and July. Therefore, it is pretty safe to fly the supersonic jets during these two periods.

#### IV. The mechanism of the radiation biological effect

##### A. The energy transfer of basic particle radiation

The biological effect of radiation depends on two factors: (1) How the radiation energy transfers from the basic particles to the tissues of the organisms. (2) The change or damage of the tissue resulting from the energy transfer. The interaction between these two factors decides the intensity and quality of the biological effect. Here, we will start with the discussion of the first factor.

When the radiation particles penetrate the cells and tissues, it will consume energy just like any other material does. The energy is consumed during ionization while the particles penetrate through organic substance, cells, and the tissue. Energy is transferred from the radiation particles to the cells and tissues. The particle travels through the tissue in a straight line. Therefore, this energy loss of the radiation is also called the straight-line energy transfer.

In other words, the straight-line energy transfer is used to describe the ionizing path and condition while the particles penetrate through the organic material. The straight-line energy transfer depends on the mass, charge, and speed of the particles, which will be discussed.

1. The mass of the particle:

The greater the mass, the faster will be the energy transfer. The particle with greater mass may lose all its energy during its passage through the tissues. The greater the mass, the faster the energy will be lost, and the denser the ionization will be. This corresponds to densely populated black dots on photographs and tissue sections.

2. The particle charge:

The straight-line energy transfer is proportional to the square of the particle's charge. The greater the charge, the denser the ionization appears and the greater the damage to the tissues. The dense ionizing path will disturb the recovery of the ionized atom or molecule. Under the radiation condition of the high-energy transfer, these ions or new molecules will be closer to each other, which will tend to break more chemical bonds in the later formation of the new molecules. The breaking-down of the chemical bonds will cause secondary ionization of the surrounding tissues and result in permanent damage. In the case of certain high-energy transfer, the ionizing path is not dense. Therefore, the affected tissues can have better chance to recover. If the energy is even higher, even though the ionizing path route is denser, less tissue will be affected due to the shorter passage. Therefore, as a whole, the total biological effect is still smaller than for low-energy transfer. It has been shown in experiment that: A heavy-water beam of  $22.5 \times 10^{12}$  eV is reduced in width to 25-100 $\mu$ m,

but its straight-line energy transfer is enhanced. As a result, the endurance to radiation of rat brain tissue is improved 4-fold. The higher the energy transfer, the denser the ionizing paths, and the more damage the radiation will cause. However, as mentioned earlier, if the energy transfer is beyond a certain level, the ionizing path will be shorter and less tissues will be damaged.

### 3. Low-energy particles:

Every cell or tissue, not just particularly sensitive parts, can be the target of radiation of low-energy primary cosmic particles. For high-energy particles, it will penetrate through the whole animal body without losing its energy completely. The low-energy cosmic radiation particles will cause a high density of ionization and high straight-line energy transfer. The local effect will show as soon as the particles enter the cell. From the observations of the ionization density and the range of its passage, it seems that the distance of penetration is short and the black dots are densely distributed. As the particle travels deeper, the passage will gradually enlarge and spread out, and the biological effect will diminish until it disappears completely. As shown in Figure 5-12, when the primary cosmic radiation particles first enter the cell, the passage is narrow and dense, but it becomes wider and less dense after the particle travels 36mm, and a star-shape figure appears, as shown in Figure 5-12(b). The spreading out causes a higher intensity of local ionization because of the increase in ionization area. The experimental results show that, for the calcium molecule, the ionization intensity is 1000r when the radius of the passage is 0.5 $\mu$ m, and it will increase by 100r if the passage radius increases to 4 $\mu$ m. The ionizing passage, mainly caused by low-energy electrons, was recorded while the space ship travelled in an earth orbit, as shown in Figure 5-13. The passage of a low-energy primary

cosmic radiation particle is shown in Figure 5-13(b).

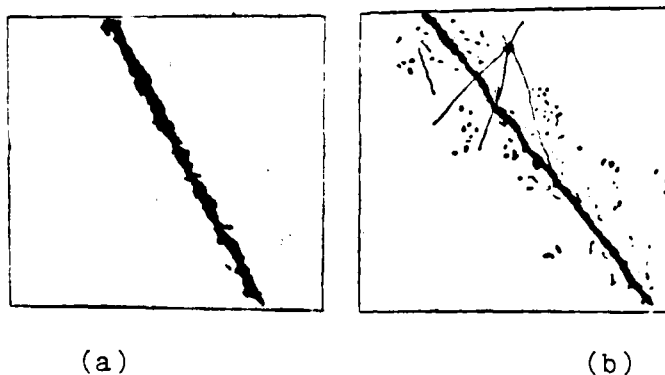


Figure 5-12. The change in ionizing path of the primary cosmic particles (atomic no.  $z=23+3$ ).

a. dense path

b. spread-out path of the same particle after 36mm of travel.

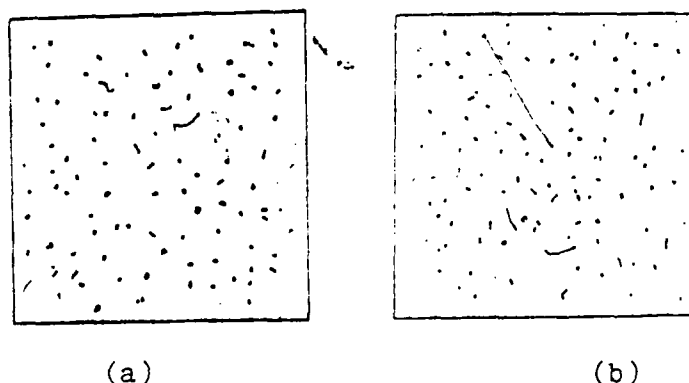


Figure 5-13. Ionizing path record taken during travel in earth's orbit.

The energy transfer is higher for the  $\alpha$ -particles than for  $\beta$ -particles with the same energy, therefore, the former is easier to protect against. The naked nuclei of the primary cosmic radiation particles have higher straight-line energy transfer. For example, the straight-line energy transfer of  $\text{Fe}^{+26}$  nucleus is 676 times higher than for cosmic radiation protons.

#### 4. The speed of the particle

The straight-line energy transfer is in inverse proportion to the speed of the particle. The higher the speed, the lower the energy-transfer. If the particle moves slower, it can stay in a certain area for longer duration. Therefore, more changes can be induced by the slow particle because it loses more energy per unit area. The particle will slow down as it passes through the tissue. When the particle reaches close to the end of the passage, where the particle stops moving, the energy-transfer will reach its climax. This phenomenon will not occur in the case of high-energy heavy particles because its speed can force it to pass through the whole target without stopping. Even though stopping occurs, it will only cause elastic or non-elastic nuclear collisions.

The damage caused by radiation particles in biological tissues depends not only on the straight-line energy transfer, but also on the penetrating ability of the radiation particle. If the particles does not have strong penetrating ability, the damage will be only limited to the surface of the organism even though the particle is very destructive. Both x-ray and  $\gamma$ -ray possess a very strong penetrating ability and can penetrate the tissues for several feet. As far as the electromagnetic waves are concerned, the shorter the wavelength, the stronger the penetrating ability and the biological effect. The radiation particle with greater mass will stop suddenly, therefore, it cannot penetrate deep into the tissue. The penetrating ability of highly-charged particles is extremely low, therefore, its effect is only limited to the body surface even though its straight-line energy transfer is very fast. For example, the  $\gamma$ -particle is highly charged and the energy-transfer is very fast, but its penetrating ability is very low. Therefore, only a piece of paper, a single layer of clothing, one pressurized suit, or a very thin layer of cabin surface made of low atomic-

weight material can block the movement of  $\alpha$ -particles. On the contrary, low-mass, low-charge  $\beta$ -particles possess a very high penetrating ability, which can penetrate through the skin and cause burning injury on the body. The cosmic-ray particles move with very high speed, therefore, possess great penetrating ability even though they have a high charge and large mass. These high-energy particles can pass through the whole body without stopping. Even the low-energy primary cosmic-radiation particles can extend 10mm under the skin surface. Protons in the inner radiation zone which surrounds the earth are in the above category. Hence, they can pass through the metal cabin surface and affect the crew members in the cabin. The samples taken from the clothes or helmets of the crews indicate that most of the passenger damage was caused by protons with energies less than  $40 \times 10^{12}$  eV from outside the space ship.

The neutral particle possesses greater penetrating ability than the charged particle. The neutron can travel deeper into tissue than the protons with the same energy.

#### B. The biological-target theory

The other factor deciding the biological effect of the radiation is the mechanism which describes how the radiation energy affects the biological tissues. There are two hypotheses: (1) direct effect on the target, the sensitive molecules (RNA, or protein, etc.) or sensitive parts of the cell (chromosome, etc.) (2) indirect effects on the cell: the radiation first affects the extracellular and intracellular molecules, which induces the release of toxin. As the toxin spreads over the cell body, damage is caused to the cells. The first hypothesis suggests that the radiation directly attacks the target and causes primary ionization which results in the damage of the cell. The second hypothesis suggests that the primary



ionization which occurred in the extra- or intra-cellular water molecules induces the release of free ions. The spreading-out of the free ions results in secondary damage to the cells. There is various evidence and reasons backing up both theories. The supporting evidences for the 2nd hypothesis are mainly collected from the laboratory: pure ingredients, such as enzymes, protein, nucleic acid, hormone, and isolated cells or tissue are used as study material. And radiation will cause the water to release the hydrogen peroxide base which is toxic to the cell. Since all the organisms and cells have water, it is very possible for the cells to release the  $H_2O_2$  base (also  $OH$ ,  $O_2$ , and  $H$ ). If we inject  $H_2O_2$ , produced in vitro, into barley seeds, abnormal changes are observed in the chromosomes which are similar to those caused by ionizing radiation. Evidence proves that many substances, such as protein, amino acid and some hormones, release some free ions after exposure to radiation. These free ions, just like the free ions of water, show the characteristics of stereoisomerism. In addition, some parts of the protein or amino acid molecules are more sensitive to radiation (e.g. the -sh and glycine in the protein) than other components in the same molecule. All these evidences indicate that ionizing radiation may cause the release of some organic free ions which can damage cells and organisms.

The direct-effect theory (the first hypothesis) can hardly explain the radiation damage caused under some conditions (e.g. how the chemicals, oxygenation, freezing influences the radiation effect on cells, tissue and experimental animals). The effect of these factors are easier understood if the secondary theory is used as interpretation. For example, oxygenation will induce the change of free ions, freezing will prevent the free ions from reaching the target, dehydration and dryness will diminish the quantity of free ions.

From the previous discussion and evidence, it can be concluded that both direct and indirect effects exist, and both effects are correlated and complementary. As a matter of fact, the biological effect of the ionizing radiation is the result of many complementary reactions which cannot be isolated from each other. From the medical point of view, the characteristic of the target is more important in deciding the effect than the mechanism. For example, a large quantity of radiation is required to cause damage to the massive cell population of the liver and striated muscle. On the contrary, if the radiation is aimed at the genes of dividing cells, only a small amount of the radiation will cause significant damage.

Before we accept the co-existence of the direct and the indirect theories, we have to admit that the radiation effect on the biological tissue will involve the following mechanisms:

- (1) The ionized particles or photons penetrates the large molecules of the organism, and directly cause mechanical damage to the cell.
- (2) The energy of the ionized particles is converted to heat in a small area which will result in heat damage to part of the body.
- (3) The ionization, caused by radiation, will cause chemical changes in the body fluid. The products (free ion) of these chemical reactions can spread to the neighboring tissues, even to the whole body and cause damage.
- (4) The compensatory reaction and recovery process can be observed in the organism after radiation damage has resulted.

Another kind of the biological effect of the radiation is also indirect. For example, if the radiation destroys the

parasites in animals or plants (but not the animal or plant itself), it will, on the other hand, enhance the growth of the animal or plant. Radiation therapy of tumors is one of these examples: The radiation can cause the cells surrounding the tumor to proliferate.

## V. Relative Biological Effect

### 1. The Significance of Relative Biological Effects

Biological effects are different for ionizing radiations with different charactersites. In radiation biology the biological effects of X-rays (X-rays with a peak value of 200-250 kV) or  $\gamma$ -rays are normally used as the standard, and when the biological effects are compared to one of these two rays: if the biological effects of the latter are greater than the former the standard relative biological effectss  $RBE > 1$ ; if vice versa the standard  $RBE < 1$ ; if the two are equal the standard RBE is equal to 1. This is expressed as

$$RBE = \frac{\text{the intensity (rads) of X-rays (or } \gamma\text{-rays which produce the same biological effects)}}{\text{the intensity (rads) of a certain radiation which produces the same biological effects}}$$

$$= \frac{\text{the biological effects of a certain radiation}}{\text{the biological effects of X-rays (or } \gamma\text{-rays)}}$$

The Relative Biological Effect is affected by the energy, the intensity, and the duration of the radiation, species, tissue, exposed area, and the quality of the biological effects (e.g. 50% lethal dosage or 100% lethal dosage; reversible damage or irreversible damage). Rough estimates of the RBE of various radiations are listed in Table 5-9 and 5-10. Taking the above

factors into consideration, the adjusted RBE are listed in Table 5-11 and 5-12.

TABLE 5-9 The RBE of various radiations

Type of radiation	Relative biological effect (RBE)	
	Material (1)	Material (2)
x-rays	1	1
$\gamma$ -rays	1	$0.8 \sim 1$
electron, $\beta$ -ray	1	1
$\gamma$ -rays	15	$20(10-25)^1$ (RBE=1 over the whole body)
$\gamma$ -rays( $10^{12}$ eV)	20	
hot neutrons	$2 \sim 5$	$5^1(--0.025 \times 10^{12}$ eV)
slow neutrons	$2 \sim 5$	$20^1(--220 \times 10^{12}$ eV)
fast neutrons ( $1-10 \times 10^{12}$ )	10	
fast neutrons ( $--20 \times 10^{12}$ eV)		$10^1$
protons ( $8.5 \times 10^{12}$ eV)		$10(8-12)^1$ (RBE =1.3, over the whole body)

1. Maybe, it is the effect on skin.

Note: If the energy of the  $\alpha$ -particle is  $3.4 \times 10^{12}$  eV, the RBE is 6.9 while the intensity is 14.5 rad, the RBE is 2.98 while the intensity is 344 rad. The RBE of the high-energy particle is usually greater than 1. But for protons of  $20-60 \times 10^{12}$  eV, the RBE is between 0.6 and 0.9.

TABLE 5-10 The RBE, rep, and the rem of various radiation

Type of radiation	Rad	RBE	rep	rem
x-ray or r-ray	0.05	1	0.05	0.05
electron		1	0.05	0.05
$\alpha$ -particle		20	0.0025	0.05
hot neutrons		5	0.010	0.05
fast neutron ( $20 \times 10^{12}$ eV)		10	0.005	0.05
fast neutron ( $>20 \times 10^{12}$ eV)		20	0.0025	0.05
protons		10	0.005	0.05

TABLE 5-11 The RBE of hot neutrons under different biological conditions

The biological effect of the radiation	Animal	RBE
LD <sub>50</sub> <sup>30</sup> (lethal dosage for 50% mortality in 30 days)	mouse	2.2
spleen impairment	mouse	2.2
impairment of the thyroid gland	mouse	2.5
decreased motosis of skin cells	mouse	2.2
testis impairment	mouse	1.7 ~ 3.2
lentitis	mouse	6 ~ 8
the duration of survival is affected	mouse	2
appearance of tumors	mouse	2
LD <sub>50</sub> <sup>30</sup> (lethal dosage for 50% mortality in 30 days)	rat	1.5
impairment of the small intestine	rat	1.7
destruction of Fe <sup>59</sup> -hemoglobin	rat	1.3

TABLE 5-12 The RBE of various radiations (compared with  $\gamma$ -ray)  
( $\text{Co}^{60}$ )

Type of radiation	Infection of the ciliary muscle	Rashes	Epilepsy	Peeling off of skin	Glaucoma
$\text{Co}^{60}$ r	1	1	1	1	1
neutron of $14 \times 10^{12}$ eV	14	2	2.3	2.3	1.2
hot neutron	0.2	0.6	0.8	0.3	0.4
electron of $730 \times 10^{12}$ eV	1	1.0	2.0	2.0	-
$\alpha$ -particles of ( $910 \times 10^{12}$ eV	2.0	0.5	2.0	0.7	-

## 2. Relative Biological Effects of Cosmic Radiation

Cosmic radiation is composed of a mixture of various basic particles and the question as to the extent its mean relative biological effect is of practical significance in aviation and space navigation. Naturally, the approximate number can be calculated from charts 5-9 and 5-10, yet the numbers in these charts are not complete and await further supplementation. In the outer radiation zone encircling the earth, the kiloelectron-volt electrons are RBE=1 as recorded in the tables. The protons of the inner radiation zone should then be divided into four categories: (1) 0.15 megaelectron-volts are RBE=11; (2) 5 megaelectron volts are RBE=2; (3) 700 megaelectron-volts are RBE=1; (4) over 700-900 megaelectron-volts whose number is still not exact.

The low energy primary cosmic radiation particle RBE is estimated to be within 2.5 - 9.0. Only one percent of primary cosmic radiation rays are heavy particles (atomic weight  $A=4$ ), yet they cause 40-85% of all biological damage. Its importance can be known but up until the present its RBE value has still not been concluded. Generally speaking, the relative biological effect RBE of cosmic radiation is close to the following numbers: Milky Way primary cosmic radiation,  $RBE \geq 10-20$ ; inner radiation zone radiation and solar flare radiation,  $RBE=1-1.5$ ; outer radiation zone radiation secondary radiation (X rays),  $RBE=1$ .

## 3. Factors Influencing Radiation Biological Effects

The biological effects of ion radiation include many factors; the following are several of the more important among them:



### 1. Dosage Rate

This points to the speed of radiation activity. With a large dosage, for example higher than a fatal dosage, when there is the same dosage of radiation, the greater the dosage rate the greater its biological effect, as is illustrated in chart 5-14.

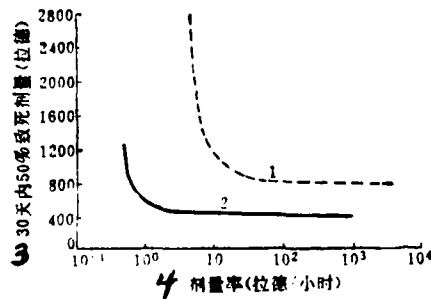


Chart 5-14 The Relationship of Dosage Rate and Fatality

Line 1 - White mouse

Line 2 - Person

3. 50% fatal dosage (rad) in 30 days

4. Dosage rate (rad/hour)

2. Stage Irradiation Time Distribution and an Organism's Recovery Abilities

If a similar dosage of radiation is given separately on several occasions, then the larger the time interval between each occasion the smaller its biological effect. For example, if it is arranged that on a certain occasion of several days of space navigation a 500 röntgen dosage is received, this will cause over 90% human fatality. If flying time is 120 days each time and each time the flight dosage is 100 röntgen, then a person can endure this 5-6 times. This type of flight then is not harmful. The distribution of irradiation time causes the harmful effect of radiation to diminish because: (1) after each occasion of irradiation

the organism can recover to some extent; (2) many occasions of irradiation promote an organism's adaptation and compensation.

### 3. Age of Receiving Radiation

When a living being is in the womb or is being born, its sensitivity to radiation is relatively high, but on the other hand, a mature organism's endurance to radiation is relatively high.

### 4. Local or Total Body-Irradiation

The biological effect of total body irradiation is more severe than local irradiation and the organ damage caused by local irradiation of a specific organ often has a stronger reaction than total body irradiation. For example, after a similar dosage of radiation irradiates the ear, the vestibular reaction is stronger than after the whole body is irradiated with the same dosage. Radiation sensitivity is different for different parts of the body; the chest-abdominal area is quite sensitive while the limbs and head are less so.

### 5. Biological Variety

The radiation sensitivity, endurance and ability of different biological varieties to recover are different. Chart 5-15 shows the sensitivity of animal varieties to radiation. For the half recovery time of animals to radiation damages, different varieties have discrepancies: the mouse is 3-8 days, the house mouse is 6-9 days, the dog is 14-18 days, the donkey is 20-28 days and a person is 20-35 days. Half recovery time is obviously related to their metabolic rate.

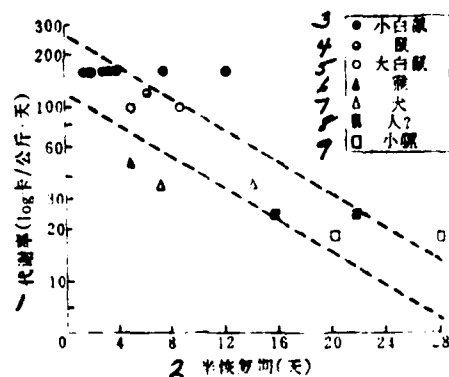


Chart 5-15 The Relation of Animal Variety Metabolic Rate and Half Recovery Time to Radiation Damage

1. Metabolic rate (log calorie/kilogram days)
2. Half recovery time (days)
3. Small white mouse
4. Mouse
5. Large white mouse
6. Monkey
7. Dog
8. Person ?
9. Small mule

#### 6. The Different Sensitivities of Different Tissues to Radiation

For example, the sensitivity of the organs in the abdominal area appears in the following sequence: the upper alimentary canal > lower alimentary canal > peripheral lymph > spleen > kidneys > liver. Total body organs show the following order: hands, feet, shoulders, neck > skin > blood forming organ, eyes, gonad > embryo tissue. The function of the brain is very sensitive to radiation; the endurance of the nervous system to radiation is relatively high. The sensitivity of various tissues to radiation is different and is related to their depths.

#### 7. Organism Functions

Whether it is a local tissue or the whole organism, when there is violent activity, sensitivity to radiation is relatively high. When moisture content is excessively large or excessively small (loss of water), this can also influence sensitivity. Hibernation causes metabolism to drop and thus radiation sensitivity accordingly decreases. Oxygenation (such as the intake of pure oxygen and the increase of the amount of pulmonary breathing) raises radiation sensitivity and lack of oxygen lowers radiation sensitivity. The general rule is the higher the tissue metabolism, the higher its sensitivity to radiation.

#### 8. Tissue Types and the Various States of the Disintegration Cycle

Various tissues show different radiation sensitivity which is generally related to its differentiation level and stage. For example, the high level tissue disintegration of the testes epithelia is relatively sensitive and thus the mature red blood cells and sperm have a specific resistance to radiation. The resistance power of cells is higher when in a normal state than when in a disintegrating state. Moreover, during the course of disintegration, radiation sensitivity is higher during the early and intermediary states than in the final states.

#### 4. The Combined Effect of Radiation and Other Conditions

Below we introduce several relatively noticeable conditions:

##### 1) The Combined Effect of Radiation and Overweightness

This has two effects: on the one hand, the combined effect

influences the organism's endurance to radiation; on the other hand, it influences endurance to overweightness. The combined effect of radiation and overweightness raises the level of an animal's endurance to radiation; however, in a small number of situations, on the contrary it causes a decrease of endurance to radiation. Long term continuous overweightness brings about a decrease of endurance to radiation. There is a relation between the influence of the combined effect of radiation and overweightness on endurance to overweightness and radiation dosage. When the radiation dosage is not large, it is possible that the influence on endurance to overweightness will not be large but when the radiation dosage exceeds a critical value, endurance to overweightness can be specifically influenced.

## 2) The Combined Effect of Radiation and Vibration

When there is vertical vibration of 70 cycles/second frequency and 0.4-0.5 millimeter double amplitude within 4 days, prior to radiation, this can cause an organism's endurance to radiation to improve. If the action is stopped in an interval period of over 5 days, this can decrease endurance to radiation. If similar vibration is brought forth after radiation, this can generally cause a decrease in endurance to radiation. If the vibration frequency is relatively high, for example 70 cycles/second (double amplitude is 0.05 millimeters), there is an unstable influence on endurance to radiation.

## 3) The Combined Effect of Radiation and Temperature Conditions

Cold and high temperatures both bring about severe radiation

sickness. Not very high temperatures such as 24°C as well as low temperatures during hibernation can be beneficial to raising endurance to radiation.

#### 4) The Combined Effect of Radiation and Gas Conditions

When the oxygen component is lower than normal (lack of oxygen), endurance to radiation can be raised. When the oxygen component is higher than normal, this decreases endurance to radiation.

#### 5) The Combined Effect of Ionizing Radiation and Other Radiation

If microwaves or magnetic fields are exerted prior to or during radiation, this can cause endurance to radiation to rise but if this is done after radiation, this can often produce an adverse influence.

#### 6) The Combined Effect of a Wound and Radiation

This generally causes radiation symptoms to worsen.

7) The effects of the combined action of radiation and vibration, overweightness, decompression, noise etc. can be seen in table 5-13.

1 有害因素	2 实验动物	3 辐射前或辐射后施加有害因素	4 辐射		对辐射耐力7的影响	8 备注
			类型	剂量(伦)		
9 振动加重	12 鼠、豚、鼠	15 辐射前4小时和24小时	—	—	21 无明显影响	—
10 振动加减压	13 兔	16 同时	18x射线	300	22 耐力降低	24 骨髓伤害提早出现
11 振动、噪声加减压	14 狗	17 同时	19x射线	200(每天9伦)	23 耐力升高	25 骨髓机能障碍改善

Table 5-13 The Combined Effect of Radiation and Certain Harmful Factors

1. Harmful factor
2. Test animal
3. Harmful factor exerted prior to or after radiation
4. Radiation
5. Type
6. Dosage (röntgen)
7. Influence on endurance to radiation
8. Remarks
9. Vibration plus overweightness
10. Vibration plus decompression
11. Vibration, noise and decompression
12. Mouse, pig, mouse
13. Rabbit
14. Dog
15. 4 hours and 24 hours prior to radiation
16. Same as above
17. Same as above
18. X ray
19. X ray
20. 200 (9 röntgen each day)
21. No noticeable influence
22. Endurance lowered
23. Endurance raised
24. Marrow damage appears early
25. Vestibular function obstruction improves

## Section Six    Radiation Damage and Other Symptoms

### 1. General Symptoms

The clinical symptoms of people harmed by radiation can be divided into the two major categories of acute radiation sickness and chronic radiation sickness.

Acute radiation sickness is produced by one large dosage of radiation. Although its initial period symptoms are different for each person yet generally speaking they are: exhaustion, weakness, nausea, vomiting, loss of appetite, headaches, localized itching, burning of the skin, lack of concentration, easy excitability, vertigo, poor sleep and a decrease in white blood cells. The initial symptoms generally last 1-4 days yet they can be as short

as several hours and as long as two weeks (see table 5-14).

剂量 (拉德)	1 症状开始时间(小时)	2 症状结束时间(小时)	3 最大表现的时间(小时)	4 症状出现率(%) (近似值)
100	3~4	10~11	6~8	5
150	2~3	14~15	6~8	30
200	~2	~20	8~8	70
300	1~2	~23	8~8	100

Table 5-14 Beginning Time, Ending Time and Occurrence Rate of Initial Symptoms of Radiation Damage

1. Dosage (rad)
2. Beginning time of symptoms (hours)
3. Ending time of symptoms
4. Time of greatest occurrence (hours)
5. Occurrence rate (%) of symptoms (approximate value)

There is a relation between the continuous time of the initial symptoms and the radiation dosage. Clinical observation: when the dosage is 100-250 biological equivalent röntgen (reb), the continuous time of the initial symptoms is 1-3 days. When 250-400 biological equivalent röntgen lasted 2-3 days, after some youths received a large dosage of 2,000-13,000 röntgen radiation (the dosage in the abdominal area was 150-160 rad), the continuous time of the initial symptoms was 4 hours. There is an important relation between the occurrence of initial symptoms and the abdominal area dosage. If the occurrence rate of radiation on the abdominal area during the initial period of symptoms is 50%, then the occurrence rate with the same dosage on the chest area during the initial period of symptoms is 33%. When there is irradiation on the head area it is 25% but if there is irradiation on the four limbs, then besides skin symptoms no other initial symptoms will



occur. Chart 5-16 shows the relation between the occurrence rate of initial symptoms and the radiation dosage.

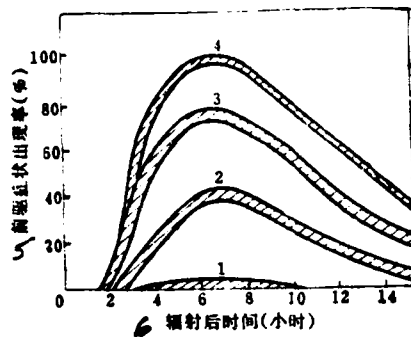


Chart 5-16 The Relation of the Occurrence Rate and Dosage of Premonitory Symptoms After Acute Radiation and the Time After Radiation

1. Dosage of 100 röntgen
2. 150 röntgen
3. 200 röntgen
4. 250 röntgen
5. Occurrence rate (%) of premonitory symptoms
6. Time after radiation (hours)

After the initial symptoms continue for a certain time, many patients were relieved for several days and the majority of symptoms disappear which showed the illness seemed to be taking a turn for the better. When the time is 1-7 days this is called the interval. After passing through this stage the condition often quickly worsens and then enters an attack.

The attack continues for about 2-4 weeks and the initial symptoms are very severe: white and red blood cells decrease drastically, there is obvious anemia, the function of the gastrointestinal tract is disordered, there is diarrhea, blood in the stool, blood oozing from the mucous membrane, hemorrhaging, oedema,

a rise in body temperature, loss of hair, cataracts, iritis and swelling of the gums. Sometimes there are complications which can even cause death.

Total body acute radiation harm indicates harm over the total body but the harm suffered by the various cells and tissues varies in severity. The several damaged cells below are the most evident: spermatogenic cells, lymph mother cells and lymphocytes, red mother cells, epithelial cells of the small intestines' gland pit, various cells of the ovaries and lower cells of the skin connective tissues. Harm to brain tissue requires a very large dosage which is possibly related to the head's skull protection. The lymph mother cells are the most sensitive to rays and with only 15 röntgen (X ray dosage), changes can appear within several hours. This is especially the case because when the lymph cells are destroyed, within several hours after radiation the lymphocytes in the blood will then decrease. The white mother cells and red mother cells of the marrow as well as the spermatogenic cells of the testes are also very sensitive and are only secondary to the lymph mother cells.

After the human body sustains 300-600 röntgen radiation once, if there is no treatment death generally occurs within 4-6 days. The cause of death is very complex but is very possibly a combination of many factors. With the most common fatal symptoms. one is unable to prevent diarrhea and this causes dehydration, electrolyte loss of equilibrium and infection. When the dosage is smaller, life can sometimes be lengthened up to 9-15 days. Some patients possibly die from obstruction to the marrow's hemopoietic blood function. Its symptoms are: at the beginning the lymphocytes

and blood platelets decrease, then there is a decline of neutral white blood cells, followed by a large amount of hemorrhaging, anemia and infection. The life of the patient is also extended 4-6 weeks; there are also those who are partially treated and protected and thus are saved. It is only necessary that the medical personnel work hard and then the most seriously ill patients can possibly be saved.

If the attacked patient does not die, there is then a recovery period. The recovery period for severe and medium radiation sickness usually begins in the fifth or sixth week after radiation. Its special feature is that the clinical symptoms of radiation sickness gradually decline or disappear. After a patient's symptoms have become stable this signifies that recovery is basically completed. Sometimes certain remaining symptoms that have not disappeared become long term sequelae or perhaps the patient will cross over to chronic radiation sickness symptoms. Medium radiation sickness can generally be restored to health 4-5 months after radiation; if treatment is effective, then recovery can be attained within 1-1.5 months. However, the recovery time for some cases has lasted as long as 1-2 years. The most commonly seen sequelae of radiation sickness are: anemia, a deficiency of white blood cells and obstruction of the alimentary canal.

Aside from the above mentioned symptoms, if the acute radiation dosage sustained is excessively high, the skin can produce radiation burns. The lightest is loss of hair (350-500 röntgen), next is erythema (500-700 röntgen), following this are blisters (750-1,000 röntgen) and most severe is the production of skin ulcers

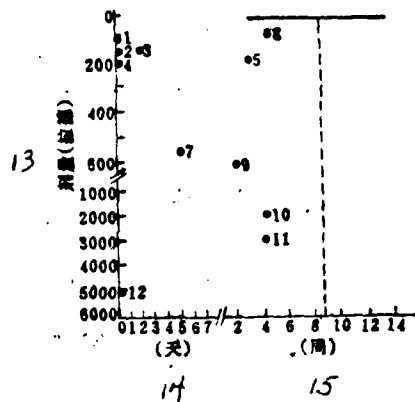


Chart 5-17 Acute Radiation Dosage  
and Symptom Appearance Time

1 - to be disgusted with eating; 2 -  
nausea; 3 - decrease in lymph corpuscles;  
4 - vomiting; 5 - decrease in platelets;  
6 - cataracts; 7 - skin rash; 8 -  
decrease in neutral cells; 9 - epilation;  
10 - epidermal peeling; 11 - oedema;  
12 - symptoms of harm to central nervous  
system; 13 - dosage (rad); 14 - (days);  
15 - (weeks)

and necrosis (over 1,000 röntgen). One time of exposure to acute radiation illness can possibly shorten the lifespan, cause genetic variation and cause the occurrence rate of tumors to rise.

Based on the analysis of clinical data, chronic radiation sickness can be listed in three types:

1. The Extremely Light Type

When the total radiation dosage is 70-100 röntgen and the dosage rate is less than 0.05 röntgen per day, it generally does not reach the level of clinical radiation sickness. When comparing its clinical symptoms with a normal person, changes in physiological functions are not clearly seen. However, the occurrence rates of some symptoms are 2-2.5 times that of a normal person and the symptoms generally appear when a person has an unhealthy body, is old and weak and lives in an unhealthy environment.

The radiation dosage accumulation under threshold can sometimes cause a little radiation sickness wherein there is nausea, exhaustion, loss of appetite, shock, temperature, diarrhea, temporary loss of hair and irregularity in heart blood vessel functioning.

2. Light Type

When the total radiation dosage is 100-150 röntgen, the dosage rate is less than 30-50 rontgen per year. The formation of radiation sickness beginning from sustaining radiation is calculated at about 2-5 years. The number of people who incur symptoms is about 20-30% of those irradiated. The symptoms are generally

light and commonly appear in an organ or system. Nerve control disorders are often quite noticeable.

### 3. Heavy Type

When the total radiation dosage is greater than 150-400 röntgen, the dosage rate is greater than 100 röntgen per year. When the total dosage is 150-400 röntgen, about 80-90% of those sustaining radiation manifest this type of chronic radiation sickness. When the dosage is greater than the above mentioned value, the symptom's occurrence rate reaches 100%. The sickness is calculated to be 1-2 years from the beginning of radiation. In general, the symptoms occur in the hemopoietic system, the nervous system, the alimentary system and endocrine systems. Yet, when the total dosage does not exceed 400 röntgen, the number of people who enter the hospital with symptoms is few. For people who sustain a 400 röntgen dosage it is only necessary to halt the continuous reception of radiation. Within 1-3 years after stopping radiation or even when the dosage rate drops below 5 röntgen per year or 0.01 per day, an organism can show apparent recovery. However, if the dosage rate is still maintained above 10 reb per year, even if it is localized irradiation, this can cause an unstable recovery of health.

## 2. The Relation of Radiation Dosage and Symptoms

The harm of sustained symptoms brought on by radiation to the human body is closely related to the radiation dosage. In order to clarify the relation between them a very important problem is safety and protection. When treating radiation sickness,

it is sometimes necessary to estimate the radiation dosage sustained by the patient from their clinical symptoms which is beneficial in determining a course of treatment. Below we introduce data and materials as reference for this field.

# 1) The Relation of Acute Radiation Dosage and Symptoms

In order to simplify narration, we have summarized related materials in table 5-15.

剂量(伦)	症状
0~25	1 无明显损害。
25~50	2 大部分人可耐受, 但出现血液和中枢神经系统功能变化。如白血球减少等。
50~100	3 5~10%的人一天内出现恶心、呕吐、疲劳、白血球减少和前庭功能紊乱。
100~150	4 一般不致重大损害, 但100伦以上有轻度损伤, 出现恶心、呕吐、疲劳、劳动能力降低等。
150~200	5 25%的人一天内出现恶心、呕吐、疲劳、白血球减少和前庭功能紊乱。
200~250	6 中度辐射损害, 但可恢复。
250~300	7 50%的人出现典型急性辐射病症状, 如恶心、呕吐、劳动能力降低等。
300~350	8 50%的人第一天出现恶心、呕吐, 有时腹泻, 继之食欲下降, 喉痛劳动能力下降。3个月内恢复健康。
350~400	9 100%的人出现急性辐射病的初期症状; 20%人2~6周内死亡。
400~450	10 50%的人30天内死亡。
450~500	11 100%的人死亡。
500~550	12 所有的人于1~2小时内出现急性辐射病症状。1~2周内全部死亡。
550~600	13 30分钟内人失能, 几小时后稍有恢复。一周内全部死亡。
600~650	14 立即失能。一周内全部死亡。

17 急性辐射在骨髓有效深度上的剂量达200拉德时, 有0.1~3.0%的人死亡。

Table 5-15 The Clinical Symptoms of People to Acute Radiation Dosages

1. Dosage (röntgen)
2. Symptom
3. No noticeable harm
4. The majority of people can endure this, yet functional changes occur in the blood and central nervous systems. For example, a decrease in white blood cells.
5. Within 1 day, 5-10% of the people have nausea, vomiting, decrease in white blood cells and vestibular function disorders.
6. This does not generally cause great harm yet at over 100 röntgen there is light harm and the occurrence of nausea, vomiting, exhaustion and decline of work ability.
7. Within 1 day, 25% of the people have nausea, vomiting, fatigue, a decrease in white blood cells and vestibular function disorders.

8. There is medium radiation harm but there can be recovery
9. In 50% of the people, there appear typical acute radiation sickness symptoms such as nausea, vomiting, and decline in work ability.
10. Within 1 day, among 50% of the people there appears nausea, vomiting, occasional diarrhea, loss of appetite and decline in throat work ability. Recovery is within 3 months.
11. There are initial period symptoms of acute radiation sickness among 100% of the people; 20% of the people die within 2-6 weeks.
12. 50% of the people die within 30 days
13. 100% fatality
14. Within 1-2 hours, all of the people show symptoms of acute radiation sickness. All die within 1-2 weeks.
15. People are incapacitated within 30 minutes and rarely recover after several hours. All die within 1 week.
16. Immediate incapacity. All die within 1 week.
17. F.N.1 When the acute radiation dosage in the marrow is sufficiently deep and reaches 200 rad there is a 0.1-3.0% death rate.

It can be seen from this table that when the radiation dosage is less than 100 röntgen the symptoms are generally light; when over 150 röntgen there is reversible medium harm; 200 röntgen can cause half of the people to show symptoms of acute radiation sickness; with a 400-500 röntgen threshold dosage there is a 50% death rate within 30 days; and when over 600 röntgen all of the people die.

Tables 5-16 and 5-17 list the symptoms treatment required and future treatment after different radiation dosages. It can be seen from the data listed in the tables that when there is less than 200 röntgen radiation, the symptoms are not serious and most people need not be hospitalized; when there is 200-600 röntgen the symptoms are relatively serious; one mainly suffers organ injuries such as in the hemopoietic tissue and especially noticeable is a decrease in white blood cells. After conscientious treatment and care there is generally recovery within 2 months.



When radiation is 600-1,000 röntgen, the symptoms are serious and 100% of the people require hospitalization. The organ that mainly suffers harm is the alimentary canal and after conscientious treatment there is hope if there is itching. When radiation is above 1,000 röntgen the nervous system mainly suffers harm and the major symptoms are also in the nervous system. After treatment, the symptoms can be alleviated but there is generally an unfavorable prognosis.

1 剂量(伦)	0~100	100~200	200~600	600~1000	1000~5000	>5000
2 治疗作用	—	9 监护	14 监护	19 有希望	24 缓和	29 缓和
3 主导器官	—	10 造血组织	15 造血组织	20 肠胃道	25 肠胃道、中枢	30 中枢神经系统
4 特征症状	—	11 白血球减少症	16 白血球减少症	21 腹泻	26 腹泻、抽搐	31 抽搐
5 死亡原因	7 无	12 无	17 血液感染	22 循环障碍	27 循环障碍和呼吸停止	32 呼吸停止
6 死亡时间	8 无	13 无	18 2个月	23 2周	28 1周	33 2天

34 ● 100伦以下为“临界以下”，100~1000伦为“治疗区”，1000伦以上为“死亡区”。

Table 5-16 Critical Symptoms F.N.1 and Treatment Required for Acute Systemic Radiation Harm

1. Dosage (röntgen)
2. Treatment Action
3. Leading organ
4. Characteristic symptoms
5. Reason for death
6. Time of death
7. None
8. None
9. Clinical care
10. Hemopoietic tissue
11. Decrease in white blood cells
12. None
13. None
14. Clinical Care
15. Hemopoietic tissue
16. Decrease in white blood cells
17. Blood infection
18. 2 months
19. There is hope

20. Gastrointestinal tract
21. Diarrhea
22. Obstruction to circulation
23. 2 weeks
24. Alleviated
25. Gastrointestinal tract, central nervous system
26. Diarrhea, tic
27. Obstruction to circulation and stoppage of respiration
28. 1 week
29. Alleviated
30. Central nervous system
31. Tic
32. Stoppage of respiration
33. 2 days
34. F.N.1 Below 100 röntgen is "below critical", 100-1,000 is the "treatment area" and above 1,000 röntgen is the "death zone".

Protons occupy a large proportion of cosmic radiation and therefore space medicine must understand the relation of proton dosage and clinical symptoms (see table 5-17).

1 器官和组织	2 引起临床损害的剂量(拉德)	3 50% 致死量 (拉德)
4 骨髓	200	200~400
5 肠胃道	400	750~800
6 皮肤	900	1450
7 眼睛和晶状体	7500	—

Table 5-17 The Dosage Threshold of Clinical Symptoms Brought on by 55-250 Megaelectron Volts of Energy

1. Organ and tissue
2. Dosage (rad) causing clinical harm
3. 50% fatality (rad)
4. Marrow
5. Gastrointestinal tract
6. Skin
7. Eyes and crystalline lens

1 总时间(年)	2 总剂量(拉德)	3 白血球缺少症(出现率的增大倍数)	4 寿命缩短(年)	5 不孕	6 白内障(出现)	7 遗传变异(出现率的增大倍数)
1	50	3x	?	0	0	2x
3	95	6x	?	0	0	3x
5	130	9x	1	0	0	4x
10	200	12x	1~2	?	0	5x

Table 5-18 Critical Dosage of Human Chronic Radiation Injury

1. Total time (years)
2. Total dosage (rad)
3. Deficiency of white blood cells (increase multiple of occurrence rate)
4. Lifespan shrinkage (years)
5. Sterility
6. Cataracts (occurrences)
7. Genetic variations (increase multiple of occurrence rate)

## 2) The Relation of Chronic Radiation Dosage and Symptoms

The major conditions are shown in table 5-18. It can be seen from this table that the major symptoms of chronic radiation are a decrease in white blood cells, a shortening of the lifespan, sterility, cataracts and genetic variations. When the total dosage reached 200 rad in 10 years most of the symptoms reached a noticeable level.

The tissue changes of the nervous system generally had little sensitivity to radiation and therefore the acute radiation dosage needed to reach above 1,000 rontgen to be able to cause harm to the nervous system. Yet, the function changes of the central nervous system were relatively sensitive to radiation. This is shown in table 5-19. For example, a 0.0007 röntgen/second dosage rate of radiation can cause light changes in behavior; with an 0.05 röntgen/second dosage there are conditioned reflex changes. This is very important to pay attention to for guaranteeing flight capabilities and flight safety.

1 神 经 系 统 反 应	2 剂 量 率 (伦/秒)
3 行为变化	0.0007
4 条件反射变化	0.05
5 脑电图失同步或兴奋性升高	0.2
6 脑电图 $\beta$ 节律增多	5.5
7 神经系统机能变化	8 17尔格/毫米 <sup>2</sup>

Table 5-19 The Chronic Radiation Dosage Rates Causing Nerve Symptoms

1. Nervous system reactions
2. Dosage rate (rontgen/second)
3. Behavior changes
4. Conditioned reflex changes
5. Disynchronization or excited rise in electroencephalogram
6. Increase of  $\beta$  rhythm in electroencephalogram
7. Functional changes in nervous system
8. 17 erg/millimeter<sup>2</sup>

3) Radiation safety protection and clinical treatment often require relatively detailed understanding of the radiation dosage threshold values of the various symptoms that occur but detailed discussion of these problems are beyond the scope of this book.

#### Section Seven The Limitations of Radiation Safety

Research on the limitations of radiation safety has important practical significance because the standard of radiation safety must be considered for airship design and the safety and protection of various radiation workers. If the radiation safety standard numerical value instability is 10% then the airship's weight design instability reaches 0.43-1.75 tons which occupies

10-35% of the airship's total weight. Therefore, when formulating the radiation safety standard, accuracy should be considered for power so as to avoid creating unnecessary waste and loss in space navigation and industrial radiation standard and protection.

Below we introduce three types of materials for reference.

1) The recommended constitutional radiation dosage safety limits are shown in table 5-20 and charts 5-18 and 5-20.

1	人平均在30年内接受的自然剂量为	4.35~5.5 (rem)
2	加上x射线治疗剂量平均3人体当量伦总计为	7.3~8.5 (rem)
3	每天最大允许剂量	0.05 (rem)
4	每周最大允许剂量	0.3 (rem)
5	每年最大允许剂量	5 (rem)
6	30岁以前最大允许总剂量	50 (rem)
7	一生的最大允许总剂量	225 (rem)
8	可允许的事故剂量(一次紧急事故暴露)	25~100 (rem)
9	急性辐射的最小致病剂量	150 (rem)
10	急性辐射30天内死亡50%的剂量阈值	450 (rem)
11	急性辐射的失能剂量	5000 (rem)
12	统计的寿命缩短(每个人当量伦)	15 5~10天
13	统计的白血球减少症事件(每个人体当量伦)	16 $1 \sim 2 \times 10^{-6}$ 年
14	遗传变异2倍于一般人的剂量	30~50 (rem)

Table 5-20 Permissible Radiation Dosage for Human Bodies

1. Average natural dosage sustained by a human in 30 years
2. The average dosage of equivalent röntgen for 3 people given x-ray treatment
3. The maximum permissible dosage per day
4. The maximum permissible dosage per week
5. The maximum permissible dosage per year
6. The maximum permissible dosage before the age of 30
7. The maximum permissible dosage in a lifetime
8. Permissible accident dosage (one time exposure in emergency accident)
9. The smallest dosage of acute radiation resulting in sickness
10. The dosage threshold value of acute radiation with a 50% death rate in 30 days

11. Incapacitating dosage of acute radiation
12. Estimated lifespan shrinkage (the equivalent röntgen per person)
13. Estimated decrease in white blood cells (the equivalent röntgen per person)
14. Genetic variation 2 times the dosage for most people
15. 5-10 days<sub>6</sub>
16.  $1-2 \times 10^{-6}$

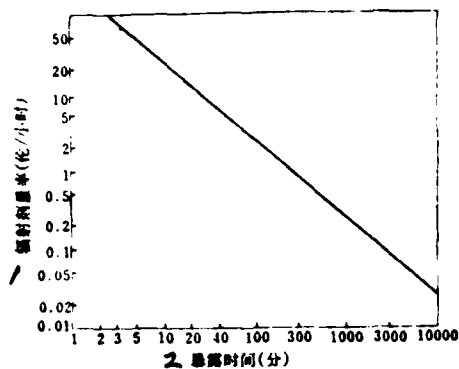


Chart 5-18 Safety Limit for Acute Radiation

1. Radiation dosage rate (röntgen/hour)
2. Exposure time (minutes)

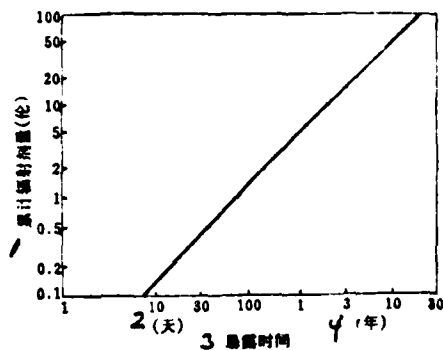


Chart 5-19 Chronic Radiation Dosage Permissible for a Person

1. Total radiation dosage (röntgen)
2. Days
3. Exposure time
4. Years

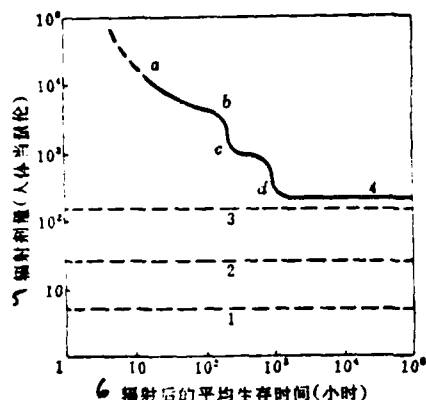


Chart 5-20 Human Radiation Safety Limit and Death Threshold

Dotted line 1: normal permissible dosage (equivalent röntgen for 5 people); dotted line 2: permissible dosage (equivalent röntgen for 25 people) under accident conditions; dotted line 3: safety limit (equivalent röntgen for 150 people); solid line 4: LD<sub>50</sub> (which is a 50% threshold). ab section: brain damage causing death (equivalent röntgen for 6,000 people); bc section: alimentary canal damage causing death (equivalent röntgen for 900 people); cd section: hematological reasons causing death (equivalent röntgen for 450 people).

5. Radiation dosage (human equivalent röntgen)  
6. Average survival time after radiation (hours)

2) The recommended constitutional and local radiation safety limits are shown in table 5-21. It can be seen from this table that the hemopoietic organ and sex glands are the most sensitive.

1 身体部分	2 每年平均剂量 (rem)	3 最大年剂量 (rem)	4 最大季剂量 (rem)
5 性腺、造血器官、眼、腺干	5	12	3
6 皮肤	10	24	6
7 手、足、前臂、腿	—	75	25

Table 5-21 Permissible Dosages for Critical Organs

1. Part of the body
2. Average dosage per year (rem)
3. Greatest annual dosage (rem)
4. Greatest seasonal dosage (rem)
5. Sex glands, hemopoietic organ, eyes, trunk
6. Skin
7. Hands, feet, forearms, knees

3) The recommended radiation safety limits in space navigation are shown in table 5-22.

1 建 议	2 最 大 允 许 量
3 一次绕地轨道飞行中保证正常工作效率的最大允许剂量	15(reb)
4 短期宇宙航行中不出现辐射病的最大允许剂量	25~30(reb)
5 一年以上宇宙航行中不出现辐射病的最大允许剂量率	10 15(reb/年)
6 建议的作为长期宇宙航行用的飞船的安全设计标准	11 5(reb/年)
7 短期宇宙航行和一次急性辐射的危险剂量	50(reb)
8 近地宇宙航行偶然辐射事件的最大允许剂量	125(reb)
9 长期宇宙航行的最大允许剂量率	12 100~150(reb/年)

Table 5-22 The Maximum Permissible Radiation Dosage (All Proposals) for Space Navigation

1. Proposal
2. Maximum permissible amount
3. The greatest permissible dosage for guaranteeing normal work efficiency in one orbital flight
4. The maximum permissible dosage for short term space navigation with no occurrence of radiation sickness



5. The maximum permissible dosage rate for over one year's space navigation with no occurrence of radiation sickness
6. Proposed airship safety design standard used for long term space navigation
7. Danger dosage of short term space navigation and one time of acute radiation
8. The maximum permissible dosage for close space navigation with a sudden radiation accident
9. The maximum permissible dosage rate for long term space navigation
10. 15 (reb/year)
11. 5 (reb/year)
12. 100-150 (reb/year)

The various safety limit proposals mentioned above are all formulated from a general principle. When practically applied, the radiation quality, its biological effects, whether it is acute or chronic and whether it has other joining functions must be considered. Furthermore, its regulation and transport to avoid blindness must all be considered.

#### Section Eight. The Prevention and Cure of Radiation Sickness

##### 1. Screen Protection

A screen is the most basic and essential protective measure against radiation. Astronauts most often rely on the airship's cabin wall as a radiation screen and secondary are their space-suits. In order to deal with sudden high strength radiation (for example, solar explosions), it is sometimes necessary to temporarily use specially screened small cabins and partially screened protective equipment as shown in chart 5-21.

Based on statistics, screened cabins are needed as protection against solar explosions when in flight for 600 days - the proton dosage encountered by humans exceeds 50 and the bio-equivalent rontgen is only 10%, the thickness of the protective

small cabin wall should be 30 grams/centimeter<sup>2</sup>. If we hope to surpass and shrink the above mentioned dosage to 1% then the thickness of the wall should be 55 grams/centimeter<sup>2</sup>.

In recent years, 20 types of related screen materials have been utilized and now there are over 100. Including water, there are organic materials (such as sand, glass and concrete, metal alloys (such as steel, nickel, lithium, aluminum, lead and other alloys), minerals (such as carbon and boride) as well as hydrogen and metal compounds. The more commonly used are water, cement, aluminum, steel, lead, paraffin wax and borax, yet because the weights and volumes of some of the materials are excessively large they cannot be used in aircraft and airships. Aluminum, lead and plastic are used most often in aircraft. Because some of the easily produced secondary radiation materials have too great a weight and volume, they cannot be used in aircraft and airships.

Stored water and food can be considered as protective in aircraft, yet no matter how it is concretely applied this design has still not yet been seen. Recently, some people have researched a type of screen material called plastic A which is a two layered specially made plastic with metal in it. The inside is inserted with peanut shells, rice husk and soy bean shells which are fin-shaped radiation absorbent materials and on the outside is a layer of metal. The protective quality of this produce is excellent, its weight is light and it is possibly adaptable for airships. Chart 5-22 shows the protective characteristics of these radiation screen materials.

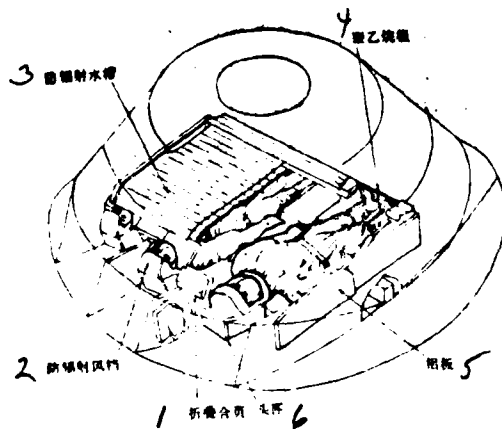


Chart 5-21 Radiation Protection Cabin

1. Folding hinge
2. Anti-radiation wind screen
3. Anti-radiation water trough
4. Polyethylene plate
5. Aluminum plate
6. Head box

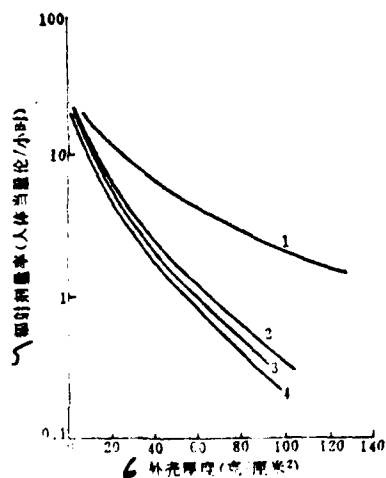


Chart 5-22 Radiation Protection Results of Different Materials

- Line 1 - Lead
- Line 2 - Aluminum
- Line 3 - Carbon
- Line 4 - Polyethylene
5. Radiation dosage rate (human equivalent röntgen/hour)
6. Thickness of outer shell (grams/centimeter<sup>2</sup>)

In order to decrease the volume and weight of the screens and increase their flexibility a partial screen method can be utilized. The protective effects of screens for the head and abdominal areas is better than for other areas and the screen effects for the abdominal area are better. Although there are some who think that head screens are superior to abdominal screens, still the majority of data shows that the screen effects for the abdominal area are twice that of the head area. When using a dog for testing, under conditions of 250 megaelectron volts and 350 rad dosage irradiation, for the abdominal area under the screen (occupying 15% of the body marrow) the symptoms were lighter and deaths fewer than when the abdominal area was above the screen (occupying 5% of the body marrow).

## 2. Medicinal Prevention and Cure

Medicinal prevention and cure is another important method for radiation sickness. There has already been research done on many drugs and these can be generally listed in three categories:

### 1. Hydrosulfides

This category includes cystamine, cystine and amino-ethyl-isothiuronium bromide hydrobromide (AET). The last mentioned has been researched extensively and is also the most effective. It can double the number of half mortalities ( $D_{50}^{30}$ ) of x-rays on mice.

### 2. Poisonous Compounds

This category includes potassium cyanate, propiodinitrile, colchicine and various depressants and stimulants of the central nervous system (for example, phenylalanine, reserpine, chlorpromazine, phenobarbital and pentahydroxyl tryptamine).

### 3. Enzymes and Hormones

The actions of this class of substances is very weak and most require a very large dosage. Yet there are also some that do not need large dosages such as adrenaline, histamines and sterol hormones, only their actions are brief and their effects small.

When tested in animals, there were not many drugs that were effective for prevention and cure of radiation harms and thus they are omitted here.

Yet, it must be emphasized that the drugs that are effective for animals do not necessarily have an equivalent effect on humans. In general clinical testing, the majority of the most effective drugs can be listed among several types. All of them are effective in treatment and most are also effective for prevention. In order to bring the drugs into full play, the time the drugs are taken is very important and it is best not long before irradiation.

A serious shortcoming of radiation drug prevention and cure is that the effective drugs have a certain amount of toxicity and moreover the effect of treatment is limited. Because of this, the use of drug prevention and cure for radiation sickness is limited within a certain sphere.

The prevention and cure effects of radiation prevention drugs are related to other environmental factors. For example, the radiation prevention and cure effects of AET drugs is noticeably low in a pure oxygen environment but the action of cystamine is not effected.

If in space navigation it is necessary to use radiation prevention drugs, they must be handled carefully because many of these types of drugs can have a negative effect on a person's endurance to overweightness, vibration, temperature and anoxia and can also negatively effect on work efficiency.

Aside from drugs, the adoption of proper nutrition can also raise a person's endurance to and ability to recover from radiation. For example, the joint use of vitamins B<sub>1</sub>, B<sub>6</sub>, C, P and other radiation preventatives can strengthen prevention effects.

The following principles should be followed when using radiation prevention drugs in space navigation:

- 1) the drug should be completely effective and not cause side effects;
- 2) the drug should act quickly and have a relatively long effective time; the effective time of supplementary drugs should, at the least, be 5-8 hours;
- 3) the drug must have low toxicity or be non-poisonous;
- 4) it cannot have a negative effect on work efficiency especially control efficiency; even a temporary effect cannot be allowed;
- 5) the means of using the drug should be convenient, for example, the oral dosage as well as volume of injection should not be greater than 2 milliliters;
- 6) its repeated use should not produce a harmful or accumulated effect on the organism;
- 7) it should not lower a person's endurance to space navigation environmental factors (such as overweightness, vibration and weightlessness).

It is very difficult to fulfil all of the listed requirements yet they must be accomplished as best as possible.

Some drugs are effective for the mechanism of radiation prevention and cure which is possibly because they emit oxygen causing the cells to have no means of using oxygen. For example, adrenaline and histamines have a reducing effect on the substance

while hydrocyanic acid and propionitrile cause cells to lose their ability to use oxygen. Other drugs compete for intake of water and have organic free radical abilities. For example, the actions of AET decreased the indirect effect of radiation. There are still theories which suppose that the protective drug screened the radiation sensitive structure in the molecules and thus caused the target not to be sensitive to radiation. If we take a sulphhydryl compound as an example, it produces a double sulphur bond internally and thus it is assumed that the reaction of the drugs hydrosulphide and the target's hydrosulphide would create a double sulphur bond. The double sulphur bond is the final source for repairing radiation damage. In other words, the hydrosulphide of the protective drug absorbs the damaging substance allowing the hydrosulphide of the original target to again act to restore the damage. Aside from this, there are also some drugs that produce preventative effects because of their inhibition of metabolism or nervous sensitivity or their stimulation of cell recovery or secondary cell repair. Generally, the radiation protection of the drugs is multifaceted and complex.

### 3. Safeguards Carried Out Based on Solar Explosion Warnings

The threat of solar explosion is quite large for high altitude flight and space navigation. Because of this, it is necessary to adopt timely protective plans after calculations, forecasts and warnings. Calculations and forecasting are indispensable protective measures. Since they can cancel, halt and discontinue flight they can be avoided temporarily.

1) Solar activities have a certain periodicity, generally one period every 11 years. The strongest solar activity time can be predicted based on this cyclic pattern.

2) Based on the statistics of historical data, there seems to be no solar explosions from November to the middle of January each year and there are only a few explosions from the middle of May to the first week in July (see chart 5-23).

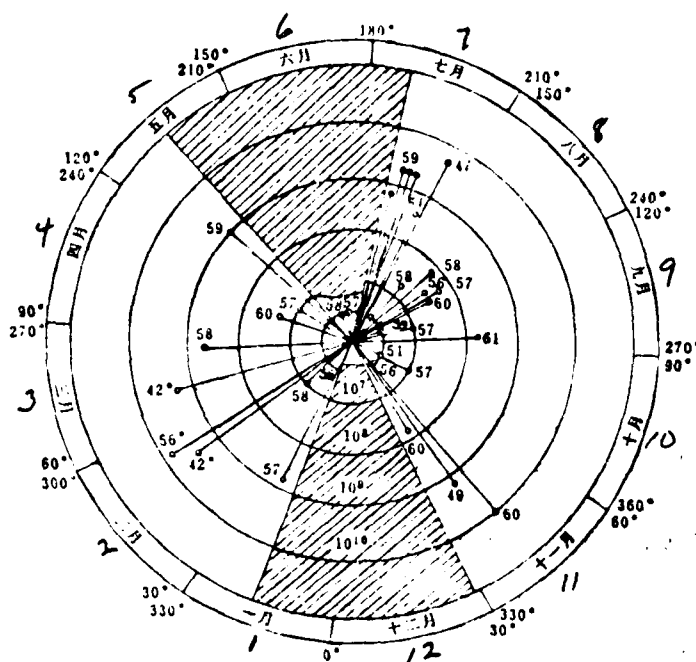


Chart 5-23 The Occurrence Rate of Solar Explosions Each Month

In the chart: the concentric circle shows the range of radiation strength, their numerical values are noted on the circular lines of each concentric circle inside the oblique line areas (unit: protons/cm<sup>2</sup>); the oblique line areas are the smallest monthly solar explosions; "0" indicates the radiation strength of each solar explosion; their adjacent numbers are the year of the explosion, for example, "57" is the year 1957.

1. January
2. February
3. March



4. April
5. May
6. June
7. July
8. August
9. September
10. October
11. November
12. December

3) Some signs usually appear several days prior to solar flares and forecasting can be carried out according to them.

4) Prior to the solar protons, optical events usually appear. The delayed time from optical events to solar flare radiation particles to reaching the earth's atmospheric layer is approximately 20 minutes to 20 hours. Because of this, the proton situation can be forecast from the optical events.

5) The installation of a radiation surveyor is also very necessary to make quick forecasts when the dosage exceeds the safety regulation.

#### 4. Other Protective Methods

- 1) The Use of Appropriate Flight Paths and Navigation Lines

Flights close to earth can adopt altitudes higher than the dense atmospheric layer (altitude of 200 kilometers) and lower than the internal radiation zone (450 kilometers) or use flight paths between the internal and external radiation zones or in an area outside the external radiation zone. The radiation dangers in these paths is relatively small. When flying out of the earth's navigation line the method of flying out from the earth's magnetic

pole area can be employed. For example, first there is close earth orbital flight and afterwards an appropriate course is chosen to fly out from the earth's magnetic pole so as to avoid passing through the internal and external radiation zones. When returning, the ship can enter an earth orbital flight path from this navigation line and then return to the earth's surface. According to statistics, there is a determined significance of the earth's internal and external radiation zones for any dip angle path long term satellite flight with an altitude of 1,000 kilometer to several earth radii. When the dip angle is less than  $50^\circ$  the altitude of the orbiting satellite is less than several thousand kilometers and the effect of the solar protons is relatively small. Yet, for the large dip angle paths, especially the space navigation outside the earth's magnetic field, the solar protons pose a serious threat. In radiation protection, these links must be grasped in order to formulate plans.

2) The Use of Freezing Hibernation (Equivalent to Animal Hibernation) to Raise Human Endurance to Radiation.

3) Selection and Training

At present, there is still a lack of effective method for selecting endurance to radiation. Because training for endurance to radiation is injurious to the human body it is still not able to be applied. The adoption of physical exercise to strengthen a person's physique is the most practical method for raising endurance to radiation.

4) Space Clear Path and Electromagnetic Screen

Some people propose the use of a "space clear path" rocket

wherein the radiation of the path passed by the airship is absorbed. There are also others who advocate the use of a strong magnetic field formed around the airship to block the high energy particles of cosmic radiation. The strength of this type of "screen magnetic field" possibly requires 10,000 gauss. In reality this is not easy to accomplish and some suggest the use of the plasma screen (also called magneto-electric screen) method. Its specific installations are: a magnetic field is established around the airship and this magnetic field is used to catch and control the absorbed electrons aside from the high energy radiation particles. If the airship maintains an electric potential greater than the surrounding environment reaching several hundred million volts this causes the high energy cosmic radiation particles to pass around and be unable to collide with the airship. According to statistics, a 100-10,000 gauss magnetic field is needed for the magneto-electric screen plan. The strength of the magnetic field in the airship cabin will not reach 100 gauss.

At present, the above mentioned protective measures 2, 3 and 4 are all still in the investigative stage.

## CHAPTER Twenty

### OTHER BIOLOGICAL EFFECTS OF RADIATION

#### Section 1 Lasers

##### 1. The Laser and Laser Instrument

The laser is a new optical technology discovered in 1960 or it can also be called light stimulated radiation technology. Lasers are a special light produced by a laser instrument. This type of light is produced when stimulated atoms, ions or molecules under the action of photons form stimulated radiation. This type of light possesses the special characteristics of "collimation" and "coherency" and thus its light pressure and destructive power is much greater than common light.

There are various types of lasers - solid gas, chemical, semiconductor and their light waves have several thousand different wave-lengths from ultraviolet to infrared. The use of laser technology in industrial health and scientific research fields is daily expanding. In recent years, it has especially caught the attention of people to use it in the areas of military affairs and national defense. In military affairs, lasers have not only become effective measures in communications, aiming, reconnaissance, observations, night vision and navigation but also they can be directly used as deadly weapons. Thus, the problem of laser harm and protection must also be given great

attention. The use of the laser in aviation and space technology is daily expanding and therefore their biological effects and protective measures have accordingly become a problem that must be resolved by aviation and space medical science.

## 2. The Harm of Lasers to the Eyes

The harm of lasers to the human body is multifaceted and include the eyes, nerve center and internal organs. Harm to the eyes and effects on vision, however, occupy a major position. The eyes are an optical system and after a light with a wavelength of 4,000-9000 angstrom (equal to  $10^{-7}$  millimeters, indicated by A) passes the cornea of the eye it goes through the eye's crystalline lens to be focused; the strength of the light falling on the retina at the eye bottom is several quantity levels higher than the light falling on the cornea. Because of this, this laser wave band is more harmful to the retina than to any other organ. Aside from the 4,000-9,000 angstrom laser, the penetration rate of spectrum lasers on the retina is relatively low and moreover the cornea is more sensitive to these spectrum lasers so that they easily create cornea blurring. The laser harm threshold value on the cornea is much lower than for the other organs (see later discussion). Whether there is harm to the retina or to the cornea, both are sufficient to cause partial or total loss of vision. Because of this, the harm of lasers to the eyes is a problem that should be seriously considered in laser protection.

Lasers are much more dangerous than common light as their rays are more "collimated" . The divergences of the light beams

only have a 0.1-10 milliradian. The more collimated the rays, the smaller the visual image reflected on the retina, and the stronger the energy density of the rays falling on the retina. Therefore, when there is the same strength of light irradiation, the irradiation strength of the laser beam on the retina will be several quantity levels stronger than common light. Under the worst circumstances, the irradiation strength of laser beams on the retina can be  $5 \times 10^5$  times greater than that entering the cornea.

Another special feature of lasers is that they possess a relatively single spectrum. The absorption rate and sensitivity of different spectrums is different for each part of the human eye. For example, a 4,000-9,000 angstrom wave-length light penetration rate is relatively large for the human eye medium yet the absorption rate in the human retina of a 5,000-5,500 angstrom light can reach to about 80%. Therefore a laser with a wave-length of 5,000-5,500 angstrom is the most dangerous for the human retina.

Another reason why lasers are more harmful to the retina than ordinary light is that laser pulse widths can be extremely short. The pulse width of the Q switch pulse laser can be as small as  $10^{-9}$  -  $10^{-12}$  seconds quantity level. The shorter the pulse width the greater the accumulation of laser heat energy on the retina and the stronger the harmful effect. A laser with a pulse width smaller than  $10^{-7}$  seconds not only has heat damage effects but its mechanical damage factors can also reach a level that cannot be ignored. The danger of a laser with a very

short width is also shown in its being relatively difficult to guard against. A person's immediate reaction is to turn the head to avoid the reflection and the natural defense reaction time of the pupil dilation reaction is much longer than  $10^{-9}$  seconds. Therefore, often when a person observes a Q switch pulse laser and cannot avoid it in time, the harm has already been created. Some lasers cannot be seen by the naked eye such as infrared and ultraviolet light so that as people cannot see it, it is even easier for them to be harmed by it.

Another problem that is worthy of attention regarding the harm of lasers to the human eye is that there is generally no pain at the time of irradiation. This is proven by cases of laser accidents in which there is burning of the retina. Because there is no pain at the time of retina injury it is especially important to watch out for this.

The harm of lasers to the retina is mainly limited by the receptor cells. Harm to the nerve fiber layer only occurs when there is great strength. The harm is possibly due to the heat effect of light absorption. When there is a Q switch pulse, the pulse width is very short and the power is very high. Under these conditions, besides the heat effect, the harm created by the laser's mechanical effect (tearing or perforation of the retina) cannot be overlooked.

As regards the area of laser harm to the retina, when harm is light it is limited to the irradiated section, medium harm generally does not exceed twice the irradiated area and when heavy, the harm area enlarges. The greater the laser's radiation (or

absorption) energy, the greater the linear increase of the damaged section's diameter.

Laser harm commonly causes a limited bruise or scar on the retina. Before recovery, there is a complete loss of vision in the damaged area. If a permanent scar forms the vision will be completely lost in this area. Yet, if the harm is just in the most visually sensitive area (the yellow spot or central depression) of the retina, then although the area of this type of limited focus is not large, it can also cause serious loss of vision. For example, in all of the laser accidents which resulted in retina burning, vision dropped from 20/20 to 20/100-20/200.

The smallest visible laser strength needed to cause harm to the retina is called the laser retina harm threshold. The measurement of the laser retina harm threshold is very important for determining the human's safety limit to lasers. Yet, there is very little data on people who have been directly measured which is possibly different from the situation in China. The data presented in tables 5-23 to 5-25 can only act as references. The relation between the laser and the retina harm threshold value is generally as follows.

1) Lasers of different wave-lengths are different for the retina's harm threshold value. Generally speaking, a 5,000-5,500 angstrom laser (such as an argon laser) is the most serious for retina harm (the harm threshold value is lowest) but a laser outside 4,000-9,000 angstrom has a relatively high retina harm threshold value. The retina harm threshold value of a neodymium



glass laser (working wavelength is 10,600 angstrom) is 5 to 8 times that of a ruby laser (working wavelength is 6,943 angstrom). This is mainly due to the fact that the eye's medium light penetration rate and retina light absorption rate change with the differences of the light's wavelength.

2) When exposure time to lasers is different, then the retina harm threshold value is different. When exposure time is about 100-400 milliseconds there is a critical point. When exposure time is greater than this critical point, the retina harm threshold value tends to be a constant. When exposure time is shorter than this critical point, the retina harm threshold value increases according to the shortening of the exposure time. This critical point is then the heat equilibrium point of the retina. When exposure time is shorter than this critical point, the threshold value strength of the laser has an accumulated effect on the retina's heat action. When exposure time is longer than this critical point, the accumulated effect of the heat is offset by the retina's heat diffusion.

3) The numerical values listed in tables 5-23 to 5-25 are all harm threshold values of single pulse lasers. At present, there are very few reference materials on the harmful effects of repetition frequency pulse lasers. Based on these materials, the harm threshold value of a repetition frequency pulse laser (calculated by the mean energy of a single pulse) is lower than a single pulse laser. Yet, when the time interval between two pulses of the repetition frequency pulse laser is greater than the above mentioned critical point (100-400 milliseconds), the

harm threshold value of the repetition frequency pulse laser is basically the same as the single pulse laser. This is mainly because when the interval time of the two pulses surpasses the heat equilibrium point of the retina, the heat effect accumulation between the two pulses is offset by the retina's heat diffusion.

See next page for Table 5-23

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Table 5-23. The effect of the continuous wave laser on the retina harm threshold value (cornea incident power milliwatts).

实验动物	2 激光器	3 角膜视象直径 (毫米)	4 暴 露 时 间 (毫秒)									
			2~4	10~15	20~25	40~70	80~120	125~135	200~250	500	1000~1200	2500
5 兔	7 氩	12 115及以下	72				17.4	AN.2				
		149	72									
	8 氩-氦	70		FN.1		2.4~7	2.4~7		2.4~7			
		—		25								
		105										
		200										25
		800										
	9 红宝石 (部分实验用钽)。(均以视网膜温度升高10℃作为伤害阈,以达到最高温度90%的时间作为暴露时间)	20			1.7							
		50				3.3						
		100						5.6				
		200							9.9			
		500									20	
		1000										
		1600										
		2000										
6 猴	10 氩	40~50		19.5		12.5		10.5~15.5			6	
		—	90	13 黄斑内9 黄斑外10			20	15 黄斑内6 黄斑外7~9				
		105~115	71~74	69	36							
	11 氩-氦	58		23	40		18~18.9	23.6	12.9	11.9	9.7	
		70			45.4			25.1	13.8	11.9	10.2	
		<100										
		100										
		230						56.1	50.3	39.8	33.1	
		250								66.2	57.0	
		—				14 黄斑内12 黄斑外						
						13.2~15.6						

FN.1 激光暴露时间不够确切。

FN.2 观察期长达48小时。无 观察期一般在1小时以内。

[illegible]

- 639

Table 5-24. The effect of the long pulse laser on the retina harm threshold value (corner incident energy: microjoule).

1 实验对象	5 激光器	13 网膜视象直径 (微米)	14 脉 冲 宽 度				
			65	200	500	560	600
2 兔	6 氩-氦	250				560	
		100~250					
	7 红宝石	250			80~200 ● F.N. 1		
		800		4500			
3 猴	8 铍	50	1600				
		50		48			
	9 红宝石	11000					
		—					4500~4700
4 人(白种人)	10 铍	50					3000
		50	1000				
		350~430					
		350~450					150
	11 红宝石	20~25		950			

● 观察期长达48小时(其他者观察期一般在1小时以内)。

(微秒)		
700	800	1500~1700
	8000	
210 ●		
		16 黄斑内420 黄斑外500
		2900
3400 ● F.N. 1		
黄斑内1100 ● F.N. 1 黄斑外2700 ●		

Table 5-24 Continued.

1. Test object
  2. Grey rabbit
  3. Monkey
  4. Person (white)
  5. Laser instrument
  6. Helium - neon
  7. Ruby
  8. Neodymium
  9. Ruby
  10. Neodymium
  11. Ruby
  12. Neodymium
  13. Diameter of retina image (microns)
  14. Pulse width (microseconds)
  15. 1,100 inside yellow spots, 2,700 outside yellow spots
  16. 420 inside yellow spots, 500 outside yellow spots
- F.N. 1 Observation period lengthened to 48 hours (other observation periods generally within 1 hour)

See next page for table 2-25

Table 5-25. The effect of the Q switch pulse laser on the retina  
bar / threshold value (cornea incident energy: Microjoule).

1 对象	2 脉冲宽度 (毫微秒)	3 网 膜 直 径 (微米)								
		2~12	20~25	25~50	90~105	150~180	250	350	400	470~520
2 灰 兔	6 红宝石	8			8					
		16	290● F.N. 1	260● F.N. 1		490● F.N. 1			390● F.N. 1	
		25~30								
		30	7~11	12	39~40	89		220		110
		30~35		280● F.N. 1						
		80					2.2			
3 猴 (恒河猴)	7 红宝石	8		22						
		8		12 黄斑内9~13 黄斑外14~26						110
		30		13 黄斑外 16.9~24.7						2700●
	8 枚	30			160~280					F.N. 2
4 人 (白种人)	9 红宝石	8	68~80							
	10 枚	30			420					

● 角膜受照射点上所接受的能量。

● 实验对象为另一种猴，而非恒河猴。

670~760	800~850	1000	1890
	300●		
	360		
300	370	710	
	350● F.N. 1		
F.N. 2			
2700●			2700

Table 5-25 Continued.

1. Test object
2. Grey rabbit
3. Monkey (Ganges monkey)
4. Person (white)
5. Laser instrument
6. Ruby
7. Ruby
8. Neodymium
9. Ruby
10. Neodymium
11. Pulse width (millimicroseconds)
12. 9-13 inside yellow spots, 18-26 outside yellow spots
13. 16.9-24.7 outside yellow spots
- F.N. 1 Energy sustained on retina irradiation point
- F.N. 2 Another type of monkey was used as test object,  
not the Ganges monkey

4) The laser harm threshold value of the retina yellow spot section (the most sensitive vision area) was lower than the area outside the yellow spots.

5) When exposure time was greater than the critical point (greater than 100-400 milliseconds), the laser retina harm threshold value calculated by the energy density or power density decreased in accordance with the enlargement of the retina image. This is because when the diameter of the visual image increased, there was a certain level of change in the retina's heat equilibrium process. If the exposure time was smaller than the critical point, the effect of the size of the retina image was not great on the retina harm threshold value which was calculated by the power density or energy density.

The above narration was limited to the acute harm of lasers. The chronic harm of lasers is also a problem worthy of serious attention. Laser workers often feel their vision is abnormal, eye discomfort, drowsiness and dizziness.



Besides being able to harm the retina, lasers can also cause harm to the cornea, crystalline lens and iris. The harm of infrared rays is relatively great in this area, especially in its burning effect. The infrared spectrum absorption rate of over 14,000 angstrom on the cornea is high and the infrared spectrum absorption rate of over 10,000 angstrom on the crystalline lens is also high. Light laser burns cause the cornea to form ashen spots or white blurry spots. Medium laser burns cause the cornea to form thick circular white injury spots. Relatively heavy harm causes the cornea to form ulcer injury spots or perforations. There are burns surrounding the injured section. When the burned section of the cornea is more profound, later there are formed radiation lines, lime changes and scars. Lasers can also cause the eye fluid protein component to rise and this effect can last several days. Relatively strong infrared and ultraviolet lasers can cause the pressure and temperature in the eyes to rise, create crystalline disclarity and even cause the development of cataracts. Even stronger lasers can cause boiling of the liquid in the eyes, the appearance of many air bubbles and the pressure in the eyes can rise to a level of explosive harm. Whether there is light or heavy cornea harm or crystalline disclarity, all of these are sufficient to weaken the transparency of the cornea and crystalline lens and thus seriously affect vision. Lasers can also cause burning and tearing of the iris. After scars are formed the pupil becomes misshapen.

In recent years, because the use of infrared and ultra-

violet lasers have been given more and more serious attention for weapons, more attention has been given to the problem of the harm threshold values of infrared and ultraviolet lasers as well as protection against them.

1) There has already been some research done on infrared laser cornea damage and the carbon dioxide gas laser (106,000 angstrom) was mainly used. With large area (up to 0.86 centimeter<sup>2</sup>) and long time (up to 30 minutes) exposure, the threshold value cornea incident energy is 150 milliwatts. When the irradiation area is relatively small (the diameter of the light beam is 1.5 millimeters) and exposure time 3 seconds, the rabbit's cornea damage threshold value is 68 milliwatts. When there is a pulse laser, an irradiation area of 12.6 millimeters<sup>2</sup> and a pulse width of 55 milliseconds, the harm threshold value is 1.2 joule/centimeter<sup>2</sup>. When the irradiation area is relatively large and the pulse width is 1 second, the rabbit's cornea harm threshold value is 1.3 joule/centimeter<sup>2</sup>; with a pulse width of 100 milliseconds, harm threshold value is 0.4 joule/centimeter<sup>2</sup>. When the pulse width is 10 milliseconds, the harm threshold value is 0.13 joule/centimeter<sup>2</sup>. Using a monkey for testing, when the Q switch erbium laser (working wavelength is 15,400 angstrom) pulse width is 50 millimicroseconds, the cornea harm threshold value is 21 joule/centimeter<sup>2</sup>.

2) Ultraviolet lasers also damage the cornea. An ultraviolet light of 2,400-3,200 angstrom creates the smallest cornea harm threshold value in a rabbit's eye lying in the area of 0.005-0.7 joule/centimeter<sup>2</sup>. The eye is most sensitive to an ultraviolet

light of 2,880 angstrom. Chart 5-24 shows the relation between ultraviolet rays and harm threshold values.

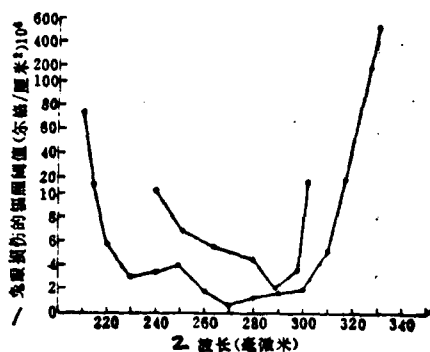


Chart 5-24 The Ultraviolet Ray Harm Sustained by a Rabbit's Eye

1. Irradiation threshold value of harm to a rabbit's eye
2. Wavelength (millimicrometers)

Each point on the curves indicates the peak value wavelength of each 10 millimicrometer wave band. The two curves in the chart are taken from two different sources.

Yet, there have been some people in recent years who think that the cornea is even more sensitive to ultraviolet light with a wavelength of 2,650-2,750 angstrom. Aside from this, relatively strong ultraviolet lasers, besides creating cornea harm can also cause cataracts. For example, ultraviolet laser irradiation with a wavelength of 3,250 angstrom and a strength of 0.85 watts/centimeter<sup>2</sup> used on a rabbit's eye, can cause disclarity in the rabbit's crystalline lens.

### 3. The Effect of Lasers on Vision Power

It goes without saying that retina and eye light trans-

mitting medium damage are naturally able to cause blurriness and obstruction to vision and this is completely organic. Aside from this, lasers can also bring about functional impairment and this is the topic for discussion in this section. The effect of lasers on the function of vision is a relatively sudden phenomena which cannot be seen clearly by the eye in a short time after irradiation. It is like the appearance of "a flash of light causing blindness" which is also called "flash of light blindness" in aviation.

Lasers and rays of similar light waves can cause the adaptation of the eyes to darkness to be destroyed and visual afterimages. Investigation of laser workers have shown this type of blurred afterimage and the phenomena of adapting to temporary darkness. This is a very important problem in modern supersonic flight (3M). This type of aircraft can fly a distance of 10 kilometers in 10 seconds and descend in altitude at several thousand meters per second; if at this moment the pilot cannot see the instruments clearly and loses control abilities then the danger created is very serious.

#### 4. The Laser Harm to Other Organs

The harmful effect of lasers to the skin was noticed early by researchers. Test results have shown that when the pulse width of a ruby laser is 0.2 milliseconds and the irradiation area is  $2.4 - 3.4 \times 10^{-3}$  centimeters<sup>2</sup>, the skin's minimal reaction threshold was 14-20 joule/centimeter<sup>2</sup> and when the Q switch pulse had a width of 10-12 millimicroseconds and an irradiation area of

0.33-1.0 centimeters<sup>2</sup>, the threshold was 0.5-1.5 joule/centimeter<sup>2</sup>. When the argon ion laser's time was 6 seconds and its irradiation area was  $95 \times 10^{-3}$  centimeters<sup>2</sup>, the threshold was 13-17 joule/centimeter<sup>2</sup>. When the carbon dioxide gas laser's exposure time was 4-6 seconds and its irradiation area was 1 centimeter<sup>2</sup>, the threshold was 4-6 joule/centimeter<sup>2</sup>. Furthermore, when a 0.5 joule ruby laser was used to irradiate the left forearm a total of 161 times within 6 months and the irradiated area had a 2 millimeter diameter, the area was fixed and results showed that on the irradiated skin area there seemed to be a decrease in skin pigmentation after inflammation.

At present, a nitrogen gas laser which works in the wavelength range of 3,371 angstrom is used for ultraviolet laser harm. The maximum harmful effect on the skin by the ultraviolet laser is a light of 2,970 angstrom. There are already materials which have shown that when in a wavelength of 2,400-3,100 angstrom, it produces a minimal skin red rash threshold value dosage which usually lies in the range of 0.003-0.05 joule/centimeter<sup>2</sup>.

Larger energy is usually required for laser to affect organs. Using animals as research subjects has shown that irradiation on the body of the subject generally requires laser strength over several tens of joule to cause harm to the liver and stomach. The damage is mostly in burns. The damage to the liver, heart blood vessel system, digestive system, lungs and spleen are basically similar. When there is serious damage there appear crater shaped hollow and solid ulcers. With light damage there is swelling and hyperemia. The damaged area generally has

clearly demarcated burns. It is significant that after one time of laser irradiation, the damage of the various tissues of the irradiated area can be very different. For example, sometimes when the irradiated skin area is lightly damaged, the internal organs are greatly damaged; sometimes when the skin and liver are noticeably damaged, the peritoneum between the two is still basically normal. These situations are possibly related to the different absorption rates of the various tissues to different wavelengths. Laser irradiation is very dangerous to the heart and blood vessel system and it can especially cause localized blood vessel embolisms.

Another problem worthy of attention is that repeated low dose total body irradiation causes endocrine changes, especially functional changes in the adrenal gland. Laser irradiation causes blood picture changes. Many small doses of laser irradiation also cause certain enzyme activity changes in the human body.

Lasers have a certain harmful effect on the central nervous system but the threshold value strength must be much higher than the eye harm threshold. Tests on mice showed that when a light beam was focused inside the brain, the mouse had very little activity after irradiation, its condition was abnormal, it stared blankly, was lethargic and trembled but did not die. Under the same conditions, a monkey showed no harm to its central nervous system. When  $75-300 \text{ joule/centimeter}^2$  and  $10,000 \text{ joule/centimeter}^2$  ruby ion lasers were used separately on a person's forehead and head, besides harm to the skin and head hair, there was no harm

to the central nervous system. Most of the threshold value data on laser harm to the central nervous system was attained when there was continuous wave and long pulse lasers and the pulse widths ranged from seconds to microseconds. The results were that laser energy of generally several tens of joule (after focusing) created serious damage to the central tissues before the mouse's head was opened. The larger the mouse the more energy needed to cause damage.

#### 5. Laser Safety Standards

At present, there are already several tens of proposals for safety limits to prevent laser harm to the retina. In the proposals prior to 1972, the maximum safety limit (all used cornea radiation power density as the standard) for continuous wave lasers was  $2.5 \times 10^{-2}$  watts/centimeter<sup>2</sup>. The smallest was  $4 \times 10^{-7}$  watts/centimeter<sup>2</sup> and the mode was  $1-5 \times 10^{-6}$  watts/centimeter<sup>2</sup>. The maximum safety limit for long pulse lasers was  $2.5 \times 10^{-4}$  joule/centimeter<sup>2</sup>, the smallest was  $1 \times 10^{-8}$  joule/centimeter<sup>2</sup> and the mode was  $1-5 \times 10^{-7}$  joule/centimeter<sup>2</sup>. The maximum safety limit for the Q switch pulse laser was  $4 \times 10^{-6}$  joule/centimeter<sup>2</sup>, the smallest was  $1 \times 10^{-9}$  joule/centimeter<sup>2</sup> and the mode was  $1-5 \times 10^{-8}$  joule/centimeter<sup>2</sup>.

There are also 20 types of safety limit proposals for infrared laser damage to the skin and cornea. Prior to 1972, the maximum safety limit established for the continuous wave laser was 8 watts/centimeter<sup>2</sup>, the minimum was 0.1 watts/centimeter<sup>2</sup> and the mode was 0.1 and 1.0 watts/centimeter<sup>2</sup>. The maximum

safety limit for the long pulse laser was  $0.1 \text{ joule/centimeter}^2$ , the minimum was  $0.01 \text{ joule/centimeter}^2$  and the mode was  $0.1 \text{ joule/centimeter}^2$ . The maximum safety limit for the Q switch laser was  $1 \text{ joule/centimeter}^2$ , the minimum was  $0.005 \text{ joule/centimeter}^2$  and the mode was  $0.1 \text{ joule/centimeter}^2$ .

The safety limit of the ultraviolet laser was:  $5 \times 10^{-7} \text{ watts/centimeter}^2$  (7 hours) and  $1 \times 10^{-7} \text{ watts/centimeter}^2$  (24 hours) for eye protection;  $1 \text{ watt/centimeter}^2$  (continuous wave) or  $1 \text{ joule/centimeter}^2$  (pulse laser) for skin protection.

On the one hand, the large amplitude of these safety standards are due to the different safety factors used by each unit (in the 10-1,000 range the mode is 10-100), and on the other hand are because the disparity of the damage threshold are very large. When a comprehensive standard is used in industry and any laser exposure time is less than 1 millisecond, the maximum permissible limit of power output is  $4 \times 10^{-6} \text{ watts}$ .

Table 5-26 lists several examples of laser safety standards.

1 建议单位	7 连续波(瓦/厘米 <sup>2</sup> )	13 长脉冲(焦耳/厘米 <sup>2</sup> )	18 Q开关脉冲(焦耳/厘米 <sup>2</sup> )	21 备注
2 国际激光安全会议(1969)	$1 \times 10^{-6}$ $5 \times 10^{-6}$	$1 \times 10^{-7}$ $5 \times 10^{-7}$	$1 \times 10^{-6}$ $5 \times 10^{-6}$	22 瞳孔直径7毫米 23 瞳孔直径3毫米
3 西德(1972)	$5 \times 10^{-6}$	14 (<1毫秒) $5 \times 10^{-6}$ 15 (1~100毫秒) $5 \times 10^{-7}$		
4 英国(算出的值)	$2.5 \times 10^{-4}$	$2.1 \times 10^{-6}$	$2.1 \times 10^{-6}$	24 红宝石激光
5 英国电子工程协会(1966)	$1 \times 10^{-6}$	$1 \times 10^{-6}$	$1 \times 10^{-6}$	25 红宝石激光
6 美国空军(1970)		16 $1 \times 10^{-4}$ (焦耳)	19 $7.5 \times 10^{-7}$ (焦耳)	26 红宝石激光
	8 (10毫秒~1秒) 9 $5 \times 10^{-3}$ (瓦) 10 (1~10毫秒) 11 $1 \times 10^{-2}$ (瓦) 12 (<1毫秒) $2 \times 10^{-2}$ (瓦)	17 $5 \times 10^{-4}$ (焦耳)	20 $4.5 \times 10^{-8}$ (焦耳)	27 氮-氦激光 28 氦激光 29 氖激光 30 氩激光

- 注: 1 连续波激光包括氦激光、脉冲激光、红宝石激光。  
2 如果光束直径小于瞳孔直径, 则安全限度可较本表所列提高。  
3 由于所用安全系数不同, 各单位所建立的标准彼此差别很大。  
4 为作量级等的同一单位的标准值有出入, 本表并列之。

Some Organizational and Governmental Laser Safety Standards Established for the Eyes



1. Proposing unit
2. International Laser Safety Conference (1969)
3. West Germany (1972)
4. England (calculated value)
5. British Electronic Engineering Society (1966)
6. American Air Force (1970)
7. Continuous wave (watts/centimeter<sup>2</sup>)
8. (10 <sup>3</sup> milliseconds-1 second)
9.  $5 \times 10^{-3}$  watts
10. (1-10<sup>3</sup> milliseconds)
11.  $1 \times 10^{-2}$  (watts)
12. (< 1 millisecond)  $2 \times 10^{-2}$  (watts)
13. Long pulse (joule/centimeter<sup>2</sup>)
14. (< 1 millisecond)  $5 \times 10^{-8}$
15. (1-10<sup>3</sup> milliseconds)  $5 \times 10^{-7}$
16.  $1 \times 10^{-4}$  (joule)
17.  $5 \times 10^{-4}$  (joule)
18. Q switch pulse (joule/centimeter<sup>2</sup>)
19.  $7.5 \times 10^{-5}$  (joule)
20.  $4.5 \times 10^{-5}$  (joule)
21. Remarks
22. Pupil diameter, 7 millimeters
23. Pupil diameter, 3 millimeters
24. Ruby laser
25. Ruby laser
26. Ruby laser
27. Helium - neon laser
28. Argon laser
29. Argon laser
30. Argon laser

Notes: 1. The continuous wave lasers include the argon laser, pulse laser and ruby laser

2. If the diameter of the light beam is smaller than the pupil diameter, the safety limit can be higher than that listed in this table.

3. Because different safety coefficients are used, there are great disparities in the standards established by each unit.

4. There are discrepancies of the standards within the same unit reported by each author and this table lists them.

## 6. Laser Safety and Protection

Laser workers should adopt safety and protection measures so as to reduce unnecessary damage as much as possible. Safety measures are determined according to the concrete conditions of laser work. Below we list some of the more commonly used

stipulations.

1) When a person directly or indirectly comes in contact with lasers, the sustained dosage must not exceed the stipulated safety limit. In laser work situations which exceed the safety limit, one should pay attention to avoid light beams and especially should not gaze at and observe the axis surrounding light beams and other reflecting lights.

2) Avoid contact with reflecting lasers from lenses, walls, furniture, controllers and instruments or have their contact strength be lower than the safety limit. There have been reports of cases of serious eye damage due to reflecting lasers from glass buttons and glass cups.

3) Prevent unrelated personnel from entering the laser work area.

4) The laser light beams must end in an unreflecting substance and no one should be in that area. As far as possible, people should be prevented from passing through an area with light beams.

5) The laser work area must be lit as best as possible so as to dilate the pupils.

6) When protective glasses and equipment are used, people must pay attention to their method of use and sphere of application. Many protective glasses can only be used for relatively narrow wavelengths and moreover, when the light beams are oblique, the protective effect is tremendously lowered. Some protective lenses produce absorption saturation for the Q switch pulse laser and thus lose their protective effect. This should be given attention to.

7) The laser instrument uses a high voltage power supply, high strength lamp (such as a xenon lamp); there is a certain contamination surrounding the instruments including x-ray, gas and chemical contamination and for all of these appropriate measures should be adopted.

8) High voltage rectifier tubes (over 15 kilovolts) can produce x-rays and this must be guarded against.

The above mentioned safety measures are only applicable in general laser work areas but in many specific laser work conditions it is difficult to accomplish absolute safety. For example, it is often difficult to accomplish the above safety conditions in military aviation and air defense because work demands should be considered first in military affairs. For example, when using the laser distance surveyor and tracker, an aircraft can use very high speed and precision for tracking targets. This type of laser, however, can very possibly produce a sufficiently high energy density incident light thus causing temporary "flash blindness" or long term loss of vision. A high powered laser used by an enemy can cause vision damage to air defense personnel. This is especially the case when using optical observing instruments because there is great danger in the gain effects of optical systems. Therefore, an effective protective means must be adopted to avoid having excessively strong lasers shine on the eyes.

There is a reflex protective reaction by the eyes against strong light, for example, light irradiation causes the pupils to quickly dilate. Yet, this type of protective effect is limited

because the pupils cannot close completely and at the same time pupil reflex requires a certain reflex time; about 0.2 seconds up to 0.4-1 second for complete pupil dilation. Strong light can also cause an instantaneous reflex reaction and this reaction time is about 50-150 milliseconds. These reactions are obviously too long for laser pulses below the millisecond level and cannot offer protective effects. Therefore, it is necessary to use worker shields.

Masks or cabin covers are one type of shield. Yet they are in contradiction with fully guaranteeing vision. In order to screen lasers and protect workers' vision or effect their observation clarity this should not be used in many military situations. The resolution of the contradiction lies in seeking a type that can screen lasers and also fully guarantee a vision protective lens material.

Among the laser protective lenses there are the reflection type, absorption type, photochemical reaction type, photoelectric type, explosion type and variable color microlite glass type. Each has their advantages and shortcomings and up to the present there is still not an ideal type. The reflection type lens affects the reflection rate because of the changes in the deflection angle and the lens deflection (strabismus or oblique fire) then affects the quality of protection. When colored glass materials are used to make the absorption type protective lens, this easily produces absorption saturation which causes a drop in the protective effect of a high powered laser. There is a relatively larger effect on vision when chemical materials are

used to construct the absorption type lens and the effect is even greater when simultaneous protection is needed for several types of lasers with different wavelengths. The reflection time of explosion type protective lenses is often longer than the pulse width of the Q switch pulse laser. Moreover, after using it once it must be discarded, its protective effect is not very ideal, it is too heavy, its structure is complex and it is not convenient to use. The reaction speeds of the photochemical reaction type, photoelectric type and variable color microlite glass type protective lenses might also be raised so that the pulse width of the Q switch pulse laser is only  $10^{-9}$ - $10^{-12}$  seconds. At the same time, it is also necessary that it quickly restore its luminosity after laser irradiation so as to avoid its negative influence on vision. Care must be taken that all of these lenses improve their affect on night vision. It is also necessary to pay attention to other related problems when selecting a protective lens. For example, when using a reflection type or absorption type lens for protection against the ruby laser (red light) and argon ion laser (green light), it is necessary to have a greater effect on red and green light vision. Yet, red and green lights are the most important in aircraft cabin lights, signal lamps as well as for airfield and communications signals. Because the use of the above mentioned protective lenses influence these two types of light vision, there can be some trouble which can even cause the need for larger improvements of aircraft cabin lighting and signal lamps system. It is mandatory to totally consider these problems when selecting

the protective lens. Aside from this, for the design of the protective lens, a wider laser protection wavelength range should be considered because new model lasers are continuously emerging and moreover the wavelengths of some lasers are changeable under certain conditions. Therefore, if the protective range is too narrow then it cannot but have limited application so that it will totally lose its protective capabilities in certain situations.

In order to adopt proper protective measures for the laser, the use of a warning system is also necessary.

What happens when there actually is flash blindness? In order to shorten the time in which the pilot cannot see the instruments, some people propose the use of temporary regulating instruments for stronger intensity lighting or the improved use of the white light lighting method. These methods can without a doubt cause earlier visual clarity of the instruments. Their shortcomings are that they destroy a pilot's adaptation to darkness to some extent and are not advantageous to seeing targets in the dark outside the cabin during night navigation.

It should be mentioned that the quality of clarity readability and cabin lighting of aircraft instruments have significant effects on the time of flash blindness. Instruments that are easily seen and read can cause a 2-10 fold decrease in the time after the flashing light. The use of red and white lighting can be considered and regulation is increased by needs of the pilots' actual visual situation.

The essence of the above narration is the problem of

visual protection against lasers. The harmful effect of lasers on the skin and other organs generally depends on the effective protection of clothes, hat and the cabin shell. Yet, from the perspective of future development, after high powered carbon dioxide gas lasers are used in vibration amplification technology the destructive affect on the human central nervous system and aircraft instruments and gas tank is still worthy of attention.

## Section Two    The Effect of Microwaves on the Human Body

### 1. The Thermal and Non-Thermal Effects of Microwaves

Some of the effects of microwave energy on organisms are reflected and some are absorbed. Most of the absorbed energy transforms into molecular kinetic energy which causes a rise in temperature. The biological effect and harm caused by heating and the microwave heating of organisms are jointly called thermal effects. Aside from these, other effects are jointly called non-thermal effects. Thermal effects occupy a superior position among all of the microwave biological effects.

The absorption energy of biotissues is different at different frequencies of microwaves. When the microwave energy frequency is lower than 1,000 megacycles and higher than 3,000 megacycles, the ratio absorbed by the biotissue is about 40%. When the frequency energy lies within 1,000-3,000 megacycles the absorption ratio is 20-100% (see table 5-27).

1 微波频率 (兆周)	2 波长(厘米)	3 量子能量近似值(电子伏)	4 有效截面的相对吸收率(%) 脂肪厚度1~3厘米, 皮肤厚度0.2~0.4厘米	6 身体	7 人的安全限度(入射功率密度, 单位为瓦/厘米 <sup>2</sup> )
400	75	$10^{-7}$	43~73	50~100	0.01
900	33	$10^{-6}$	51~89	20~100	
3000	10	$10^{-5}$	18~50		0.02
10000	3	$10^{-4}$	41~50	50	

Table 5-27 The Relative Ratio of Biotissues to Microwave Energy

1. Microwave frequency (megacycles)
2. Wavelength (centimeters)
3. Quantum energy approximate value (electron volts)
4. Relative absorption rate (%) of effective section
5. Fat thickness, 1-3 centimeters; skin thickness 0.2-0.4 centimeters
6. Body
7. Human safety limit (incident power intensity, unit is watts/centimeter<sup>2</sup>)

See table 5-28 for the reflection rate of the biotissues different and separate interfaces to different frequency microwaves. In other words, there is a disparity in the thermal effect of different frequency microwaves on organisms. The higher the energy absorption rate, the greater the thermal effect. The different ratio of energy absorbed by the organism at different frequency microwaves is related to the different permittivity and electric conduction of biotissues under different frequencies.



表5-28 生物组织分界面对微波的反射系数

微波频率(兆周)		100	200	400	1000	3000	10000	24500	35000
界	3 空气-皮肤	0.758	0.684	0.623	0.57	0.55	0.53	0.47	
2	4 皮肤-脂肪	0.340	0.277		0.231	0.19	0.23	0.22	
面	5 脂肪-肌肉	0.385	0.352	0.300	0.281				

Table 5-28 The Reflection Coefficient of Biotissues Separate Interfaces to Microwaves

1. Microwave frequency (megacycles)
2. Interface
3. Air - skin
4. Skin - fat
5. Fat - muscle

Research tests have already verified the thermal effect of microwaves. Starting from this point, microwave harm and high temperature harm are similar. At present, there is still debate on whether a non-thermal effect of microwaves exists and what its mechanism is. Those who advocate the existence of microwave non-thermal effects suggest various mechanism such as the field force effect, photochemical reaction and electromagnetic resonance effect.

## 2. The Penetration Force and Deep Thermal Effect of Microwaves

The ability of microwaves to be absorbed by biotissues can be used as an absorption coefficient (centimeters<sup>-1</sup>) for measurement and can also be used as the absorption rate (%) for measurement. The absorption rate represents the percentage of incident microwave energy absorbed by the tissue. Thus, the absorption coefficient shows the ability of microwaves to cause tissue heating. The formula for calculating the absorption

coefficient is:

$$\text{absorption coefficient (centimeters}^{-1}\text{)} = \frac{\text{the heating rate (microcalories/centimeter}^2 \cdot \text{seconds) of each unit volume of biotissue}}{\text{microwave strength (microcalorie/centimeter}^2 \cdot \text{seconds)}}$$

The absorption coefficient changes in accordance with the microwave frequency. For example, the skin absorption coefficient for a 10,000 megacycle microwave is 2.5 (centimeters<sup>-1</sup>) and the absorption coefficient is 0.6 (centimeters<sup>-1</sup>) for a 3,000 megacycle microwave. The reciprocal of the absorption coefficient is called the penetration depth and its unit is centimeters. The penetration depth indicates that with this depth, the microwave strength lowers to 1/e of the incident strength and e is the base of the natural logarithm. Thus, at this depth, the microwave strength drops to 1/3 the weakness of the incident strength. The penetration depth of a 10,000 megacycle microwave on the skin is 4 millimeters and the penetration depth of a 3,000 megacycle microwave is approximately 16 millimeters. The penetration depths of different tissues is different for varying frequency microwaves. Generally speaking, in the over 100 megacycle frequency range, the shorter the microwave wavelength (the higher the frequency), the lower the penetration force. The thermal effect of microwaves below 1,000 megacycle is relatively great on deep tissues. Most of the microwaves above 3,000 megacycles are absorbed by the skin and rarely penetrate the deeper tissues.

This special phenomenon of microwave heating is called the

deep thermal effect and its specific manifestations are:

(1) When microwaves with frequencies lower than 3,000 megacycles (especially microwaves below 1,000 megacycles) were used for heating tissues, it was discovered that their thermal effect on deep tissues such as muscles had better heating effects than the use of infrared and other methods and this was especially evident for people with relatively thin subcutaneous fat.

(2) The lower the microwave frequency the better the heating effect of deep tissues such as muscles; the effect of microwaves with frequencies below 1,000 megacycles on muscles often exceeded the heating of fat although the fat is closer to the surface of the skin than the muscles. Most of the microwave energy can penetrate fat and enter deep tissues such as the muscles.

(3) When human skin and tissue is heated to a certain level, there occurs a compensation reaction in the human body and within this reaction most outstanding is the acceleration of the peripheral blood flow. After the blood flow accelerates, the heat of the heated tissue is quickly moved away thus causing the temperature of the heated tissue to drop again. This type of effect generally occurs after the skin is heated for 10-20 minutes. This type of blood flow acceleration reaction of the skin is greater than the subcutaneous tissue and therefore similar heating causes the temperature drop of the skin due to the blood flow reaction to be greater than the subcutaneous tissue. As a

result, after 10-20 minutes of irradiation, skin temperature is lower than that of deep tissues. Because the penetration force of infrared ray irradiation and other methods is low, the great majority of energy is absorbed by the skin and does not reach the deep tissues. Therefore, the deep thermal effect does not occur. It is reasonable to say that the special feature of the deep thermal effect is microwave heating. This type of effect often causes surface skin temperature not to be too high, and not to reach the level of the pain threshold but it does cause subcutaneous tissue temperature to reach a level which creates harm. This is to say, it is possible that prior to realizing heat pain deep tissue harm has already been created. This has a certain danger for tissues with slower blood flow or body fluid circulation such as the testes and crystalline lenses. For example, when there is an artificially caused rise in tested temperature of 10-20°C but there is still no acute pain felt on the surface skin. In this way, when a person does not yet feel pain in the scrotum, harm has already been done to the reproductive function.

From the point of view of medical treatment, this special characteristic of microwaves is suitable for carrying out heating physiotherapy for deep tissues. In the past, the frequency of the microwave heaters used in physiotherapy was about 2,450 megacycles. Based on the above mentioned reasons, microwaves below 1,000 megacycles can be proposed for revised use, for example 900 megacycles, so as to increase the physiotherapeutical effects on deep tissues.

### 3. Some Factors Influencing the Microwave Thermal Effect

The thermal effect of microwaves is influenced by many factors. We have already discussed the important influences of microwave strength, exposure time, frequency, the quality of biotissues and the depth of irradiation on the microwave thermal effect and below we will further discuss several problems that cannot be overlooked.

#### 1. Skin Depth and the Level of Tissue Moisture

Generally speaking, dry tissues absorb more energy than wet tissues. When the skin depth is relatively great, 0-0.4 centimeters, the heat absorption rate of the adipose layer is relatively high.

#### 2. Interval of Time

If the time interval between each two pulses of the pulse microwave is shorter than the heat loss time (about 0.3 seconds), then a heat accumulated effect is produced. If it does not produce a heat accumulated effect then its effect can only be equal to the effect of a single pulse.

#### 3. Microwave Irradiation Effect

The effect of one time of acute microwave irradiation is greater than the effect of irradiation in stages. When the interval time is 2 times of radiation in 4 days, not very strong microwave irradiation in stages can possibly have a certain accumulated effect. When the time interval is longer than 7 days, the accumulated affect can be overlooked. This means that the harm of chronic microwave irradiation can be recovered within

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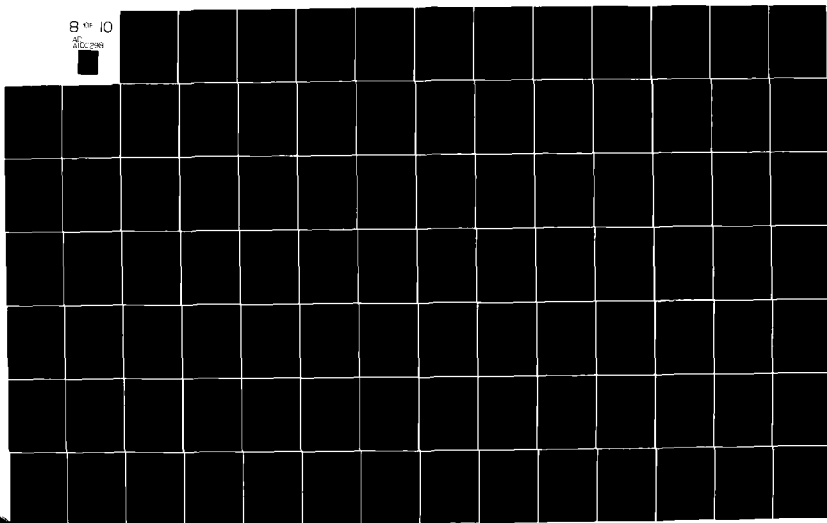
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4-7 days. However, if the microwaves are very strong, each time of irradiation can cause noticeable harm. Therefore, the interval period must be longer than the harm and after complete recovery the accumulated effects can be eliminated.

#### 4. Anaesthesia, Drinking and Scattering of Heat

Anaesthetics such as pentobarbital sodium, chloroform and morphine cause microwave irradiation thermal reaction to increase.

#### 5. Tissue Initial Temperatures and Environmental Temperatures

The lower the tissue initial and environmental temperatures, the lighter the harm created by the microwave thermal effects. This situation is similar to that of high temperature thermal irradiation.

#### 6. The Influence of Humidity and Air Flow Speed

When the humidity in the environment is relatively great, the microwave effect is also great; when the air flow speed in the environment is relatively fast, the microwave thermal effect drops.

#### 7. The Irradiation Area and Position

There are sometimes great disparities in the thermal effects of different irradiation areas.

#### 8. The Reflex Effect of Tissues on Microwaves

Some separate tissue interfaces have relatively large reflex effects on microwaves and thus influence the thermal effect of microwaves. The reflex effect of some tissues in certain areas is especially strong on certain frequency micro-

waves and thus produce "heat points" on certain areas close to the tissue.

#### 9. An Organism's Compensation Reaction

If there is a blood flow acceleration reaction, a body temperature regulation reaction and muscle contraction (evasion), all of these can cause a weakening of the microwave thermal effect.

#### 10. The Combined Effect of Microwaves and Radiation

The following cases are further explained for situations that are more complex. Several months up to one year ago living dogs were again given microwave irradiation (165 milliwatts/centimeter<sup>2</sup>, 3,800 megacycles) after sustaining 30 days of 50% and 80% fatal dosages of ion radiation. These dogs had rises in their anal temperatures, their blood cells rose above tolerance and their body weight dropped. All of these reactions were greater than before sustaining radiation. Yet, before the dogs sustained 2,800 megacycle pulse microwave irradiation, their lifetimes were often longer than before microwave irradiation when under x-ray irradiation. With the simultaneous use of 2,800 megacycle microwaves (100 milliwatts/centimeter<sup>2</sup>) and peak value voltage 250 kilovolt x-rays (the dosage was 720 röntgen, the dosage rate was 2 röntgen/minute), it was also seen that these dogs had relatively early recoveries from deficiencies of white blood cells caused by ion radiation. Yet, if the radiation dosage rate was relatively high (4.6 röntgen/minute), this condition was not seen. Generally, the combined effect of microwave and ion radiation is very complex and still awaits further research and clarification.



#### 4. The Body Temperature Rises and Fatality Caused by Microwaves

The main effect on the whole body by microwave irradiation is the thermal effects which has already been explained above. If heating surpasses the organism's temperature regulation ability limit then the normal temperature balance will be destroyed and that will create burns. If high temperature reactions of the whole body including acid poisoning, excessive breathing, tears, perspiring, heart blood vessel reactions, tics and respiration obstruction are not properly treated, this can endanger life safety. Autopsies on animals have shown that their pathological changes were similar to high temperature deaths.

Whole body high temperature reactions of microwave thermal effects can be divided into two stages. The first stage is the thermal reaction period in which there is a rise in the respiration rate, a drop in the respiration depth and gasping for breath. This stage generally lasts for 20-25 minutes. Following this, the organism undergoes a noticeable compensation reaction wherein heat balance occurs. This is the heat balance period. Generally, at the 60th minute after continuous exposure, if microwave exposure continues the organism's heat storage exceeds its permissible limit and thus the heat equilibrium is destroyed and the organism collapses or even dies. This is the heat imbalance period.

#### 5. The Harmful Effects of Microwaves on the Eyes

The harmful effects of microwaves on the eyes is an important aspect of microwave harm. Microwaves can cause blurri-

ness and cataracts in the eye's crystalline lens and stronger microwaves can also create harm to the cornea, iris and the eye's anterior chamber. Serious harm to the eye by microwaves causes crystalline lens blurriness and cataracts. There are two types of major harmful situations. One is acute harm caused by high strength microwaves. This type of harm is commonly accompanied by harm to the cornea, iris and anterior chamber and blurriness mainly appears immediately under the crystalline lens. This develops and dissolves and even causes complete blurriness. The other type occurs when there is relatively low strength microwave irradiation. For example, with relatively longer irradiation of  $100 \text{ milliwatts/centimeter}^2$  microwaves, a dormancy period of several days to several weeks, is needed for the development of crystalline lens blurriness. The harm is chiefly seen in the crystalline lens posterior cortex area including granular or small bubble harm. Cataracts can also be produced from the accumulated effects of many times of microwave irradiation with strengths below the threshold value. If the level of crystalline lens blurriness caused by the microwaves is not serious then it often dissipates after appearing and completely disappears within several weeks or only a scar remains. Serious crystalline lens harm is irreversible.

The harmful effect of microwaves on the eyes is related to its frequency. Microwaves within the frequency range of  $0.8 - 65 \times 10^9$  cycles can cause crystalline lens blurriness. The lower the microwave frequencies within this range the lighter

the harm (see chart 5-25). The numerical values on the curves in the chart indicate the microwave frequency (kilomegacycles/second) and the dotted lines are taken from a multiple of sources.

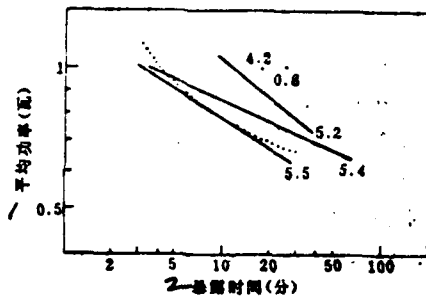


Chart 5-25 The Threshold Values of a Single Time of Microwave Exposure Producing Crystalline Lens Blurriness (Cataracts)

1. Average power (watts)
2. Exposure time (minutes)

The harmful effect of the pulse microwave is similar to that of the continuous microwave. From the test results shown in chart 5-26, the harm of an over  $7 \times 10^9$  cycle frequency microwave on the eye is mainly to the cornea, iris and anterior chamber; harm to the crystalline lens is rarely seen. This is because the penetration force of this type of frequency microwave is relatively low and therefore harm is generally limited to the surface of the eye.

The earliest appearance of crystalline lens harm after acute microwave irradiation is the crystalline lens oedema which

is irreversible and this does not necessarily cause crystalline lens blurriness. Oedema can sometimes last as long as several days to several weeks before disappearing. Yet, if the harm is relatively serious or if another dose of microwave harm is added during the oedema period, the harmful effect can accumulate and cause crystalline lens blurriness. This explains why repeated microwave irradiation with strengths below the threshold value can cause crystalline lens blurriness.

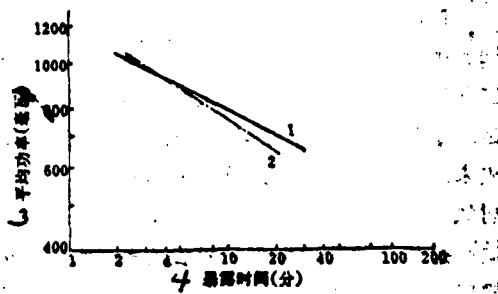


Chart 5-26 Comparison of the Threshold Values of Pulse and Continuous Microwaves Which Produce Crystalline Lens Blurriness (Cataracts) - (Microwave Frequency of 5.5 Megacycles/Second)

- Line 1 - Continuous microwave
- Line 2 - Pulse microwave
- 3. Average power (milliwatts)
- 4. Exposure time (minutes)

## 6. The Influence of Microwaves on the Senses

### 1. Vision

Besides causing visual organ harm (cataracts) and thus influencing vision, microwaves can cause after effects that produce changes, the light field of vision to increase and the color

perception reception area to shrink. These effects, however, are not very steady.

## 2. Hearing

Microwaves can cause the auditory threshold to shift (temporary threshold shift). For example, when a 50 megacycle radio wave went through an electrode and was passed on to a person, it was discovered that the person's pure sound auditory threshold of 1,000 cycles/second rose 4-6 decibels and the pure sound auditory threshold of 4,000 cycles/second rose 6-10 decibels. The higher the sound frequency the longer the auditory recovery time. Microwaves can not only cause human hearing to decline but can also cause auditory reaction time to lengthen. The effect of microwaves with wavelengths of 10 centimeters was stronger than those of 30 centimeters. Microwaves can also cause changes in auditory space perception.

## 3. Smell

Based on investigations of 358 people working in a 10-100 centimeter wavelength range, it was discovered that the smell threshold distribution curve became bimodal (the smell threshold distribution curve of most people is unimodal) and moreover tended towards the low value extreme. For people who were exposed to power density microwaves of several milliwatts/centimeter<sup>2</sup>, the longer their work time the more deficient their sense of smell. It was practically shown that for people who were continually exposed to 1 milliwatt/centimeter<sup>2</sup> microwaves, when the work period was greater than 1 year and less than 6 years, the

change in sense of smell was relatively great but the reason for this is still not clear.

#### 4. Skin Sensations

Microwaves can cause the skin to feel hot. The fingers are more sensitive than the face. The higher the microwave strength, the greater the irradiation area and the shorter the time of heat sensation. Higher strength microwaves can cause heat pain or burning pain on the skin. See table 5-29 for the threshold values of microwave strengths which cause human skin to feel heat and burning pain.

(微波频率3000兆周, 照射面积9.5厘米<sup>2</sup>)

1 阈值功率密度(瓦/厘米 <sup>2</sup> )	2 暴露时间(秒)
3.1	20
2.5	30
1.8	60
1.0	120
0.83	<180

注: 1. 在照射面积为53厘米<sup>2</sup>, 暴露时间3分钟时, 不可耐痛阈为560毫瓦/厘米<sup>2</sup>。

2. 以频率2456兆周的微波照射大腿, 将引起不可耐痛的阈值为0.11瓦/厘米<sup>2</sup>; 频率900兆周的微波上述阈值为0.22瓦/厘米<sup>2</sup>。

Table 5-29 Human Skin Non-Endurance Burning Pain Threshold to Microwaves (Microwave Frequency 3,000 Megacycles, Irradiation Area 9.5 Centimeters<sup>2</sup>)

1. Threshold value power density (watts/centimeter<sup>2</sup>)

2. Exposure time (seconds)

Notes: 1. When the irradiation area is 53 centimeters<sup>2</sup> and exposure time is 3 minutes, the non-endurance threshold is 560 milliwatts/centimeter<sup>2</sup>.  
2. Irradiation with 2,456 megacycle frequency microwave will cause the non-endurance pain<sub>2</sub> threshold value to be 0.11 watts/centimeter<sup>2</sup>, when the microwave frequency is 900 megacycles the above mentioned threshold value is 0.22 watts/centimeter<sup>2</sup>.

## 7. The Influence of Microwaves on the Nervous System

### 1. The Penetration Force of Microwaves on Head Tissue

The peripheral tissues of the skull (skin, fat, muscles, skeleton etc.) have a noticeable attenuating effect on the electromagnetic field. 1,000 megacycle (300-1,500 megacycle) microwaves have the greatest penetration force on head tissues. The reflection rate of low frequency microwaves is relatively high for head tissue. The absorption of high frequency microwaves by tissues outside the brain is relatively strong and therefore microwaves in the area of 1,000 megacycles are quite dangerous to the brain.

### 2. The Effect of Peripheral Nerve Stimulation

Microwave irradiation of the peripheral nerve causes biotonic reactions in animals including: (1) rises in blood pressure and respiration rate; (2) lowering of the electric potential amplitude of the electroencephalogram; (3) defense reactions such as the escape reaction.

### 3. Tissue Pathological Manifestations of the Nervous System

Brain damage caused by stronger microwaves includes white and grey substance brain damage, brain stem damage, as well as nerve axon and dendron damage. The dendron tips thicken and the nodes disappear. Besides this, there is also nerve tract, spinal cord and autonomic nerve damage.

### 4. Changes in the Electric Activity of the Central Nervous System

Research on the electroencephalograms of 120 persons

working for a long period of time in a centimeter wave environment showed that there were many subnormal changes in these people's electroencephalograms. People who used drugs to induce microwave work for over 3 years had higher positive reactions on their electroencephalograms than normal people.

#### 5. Vegetative Reactions and the Influence of Unconditioned Reflexes

Low strength microwave irradiation causes the skeletal reflex dormancy period to shorten and high strength microwaves cause its dormancy period to lengthen. Microwave irradiation can also inhibit the tics of mice when they are in noisy conditions. Microwaves can also cause vestibular and vagus nerve vegetative reactions. Microwave irradiation of peripheral nerves can also cause changes in the conduction rate, excitability, refraction period and latent period of these nerve reflexes.

#### 6. Major Symptoms

People who do microwave work for a relatively long period of time often have central discomfort symptoms, mainly exhaustion, headaches, drowsiness, memory deficiency loss of appetite, pain in the eyes, hand quivering, a lowering of work efficiency and heating of the skin and limbs. Clinical investigations have also discovered that some people have various different symptoms. Generally speaking, they are heart expansion, heart murmurs, changes in electrocardiograms, an increase of the thyroid gland I<sup>(3)</sup> absorption, an increase of serum albumin, a lowering of the sense of smell, trichomadesis, function attenuation and some nerve symptoms. These symptoms are generally reversible and



disappear some time after leaving the microwave work area. Yet, those who recover from microwave work can later have relapses.

#### 8. Other Physiological Effects of Microwaves

The physiological effects of microwaves are multifaceted and complex; some seem to be protopathic but most symptoms are derived or induced thermal effects. This problem is only discussed below in general.

##### 1. General Physiological Changes

Body temperature rises brought on by microwaves can cause a series of high temperature physiological reactions in the human body and among them respiration, digestion and circulation reactions are quite evident. These are manifested in the acceleration of the pulse and blood flow, an initial rise in blood pressure which gradually drops; respiration quickens and there is development to the stage of respiration obstruction. There are also rises in the metabolism rate, blood sugar rises, the composition of phosphorus in the blood changes, the specific volume of blood rises, there is an increase of red blood cells and granular cells and there is a decrease in the number of erythroblasts, lymphoid cells, white blood cells and neutrophil cells, there is a rise in thyroid gland activity, body weight drops, there is an increase of gastrointestinal peristalsis and saliva secretion, an increase of potassium chloride and calcium and the amount of glucose drops. Whether this series of changes is completely a side effect of the microwave thermal effect or is partially due to direct stimulation by the microwaves is very

difficult to distinguish clearly.

## 2. The Effect of Harm Done to Sperm Production in the Testes

The effect of microwaves on the testes is quite noticeable and certain. Besides causing oedema of the testes tissues and degeneration of the epithelial cells, the most noticeable changes are a decrease in the spermatid, the primary spermatocytes cannot further split and reproduce and under normal conditions the temperature in the scrotum is maintained below  $37^{\circ}\text{C}$ . When a person has cryptorchidism, their testes are unable to come down from their abdominal cavity so that their testes do not have mature sperm. Artificial heating of the scrotum to over  $37^{\circ}\text{C}$  can stop spermatocyte cell division. Based on the above facts, microwave irradiation causes changes in the seminal duct epithelium and the loss of the ability of sperm production which is an after effect caused by the microwave thermal effect.

## 9. Microwave Safety Standards

There are many views on the problem of microwave safety standards. Some, based on the tissue harm threshold value caused by microwaves, consider that microwaves below 100 milliwatts/centimeter<sup>2</sup> generally do not create noticeable irreversible tissue harm. Because of this, after selecting a safety coefficient of 10, the safety limit is fixed in the area of 10 milliwatts/centimeter<sup>2</sup>. The safety standards now employed by some nations are basically founded on this view. Each nation formulates their own standards based on work conditions and

living situations. Because of this, safety standards cannot be borrowed indiscriminately by other nations. Table 5-30 summarizes some of the conclusions of foreign materials.

Table 5-30 Microwave Safety Standards

(I)

A. Occupational and Environmental Protection Stipulations

1. Under normal environmental conditions, when the electromagnetic frequency rate is 10-100,000 megacycles and the exposure time is longer than 6 minutes, within any 6 minutes the average power density does not exceed 10 milliwatts/centimeter<sup>2</sup>.

2. When the exposure time is shorter than 6 minutes, the average power density does not exceed 1 milliwatt /centimeter<sup>2</sup>.

The above mentioned safety standards are suitable for whole body or localized exposure as well as occupational exposure but is not suitable for special environments such as high temperatures. Under high temperature conditions, the safety limit must be lower. In a low temperature environment, the safety limit can be appropriately raised.

B. Stipulations for Military Use

The permissible exposure time for 300-300,000 megacycle frequency microwaves is

$$T_p = \frac{6,000}{X^2}$$

In the formula  $T_p$  is the permissible exposure time (minutes) in any 1 hour<sup>2</sup> and  $X$  is the microwaves power density (milliwatts/centimeter<sup>2</sup>).

This formula is only suitable for power densities below 100 milliwatts/centimeter<sup>2</sup>. Therefore, when exposure time is less than 2 minutes there is little practical significance.

C. Proposals by the Health Department

When the microwave frequency is  $10^8$ - $10^{11}$  cycles/second, the safety limit is:

1. The average power density does not exceed 10 milliwatts/

centimeter<sup>2</sup> and each day the exposure time does not exceed 8 hours (continuous exposure).

2. The average power density does not exceed 10-25 milliwatts/centimeter<sup>2</sup>, the exposure time in any 1 hour of an 8 hour work day does not exceed 10 minutes (uncontinuous exposure).

3. The average power is not allowed to exceed 25 milliwatts/centimeter<sup>2</sup> in any situation.

## II

1. Irradiation strength cannot exceed 0.01 milliwatts/centimeter<sup>2</sup> during a whole work day.

2. Irradiation strength of 0.1 milliwatts/centimeter<sup>2</sup> cannot exceed 2 hours during any given work day.

3. Irradiation strength of 1.0 milliwatts/centimeter<sup>2</sup> cannot exceed 15-20 minutes during any given work day. Moreover, protective glasses must be worn.

Note: Based on calculations, microwave strength of 10 milliwatts/centimeter<sup>2</sup> is equal to the electrical field strength of radio waves with continuous radiation strength of 200 volts/meter.

### 10. Protective Measures Against Microwaves

The important feature of protective measures against microwaves should be shields. Besides the shields and protective screens used in work areas, the use of protective clothing by each person is also an effective measure. The fundamental design is the use of a metallic reflex material as the middle layer which will reflect away the microwave energy. A layer of electrolytic insulation material (such as chloroprene rubber nylon fabric) is added on to the outside of this shield. The innermost layer is a relatively strong cotton layer. The shortcoming of this type of clothing is that it is cumbersome, activity is not convenient and it does not breathe freely so that it can only be used under cold

conditions. The major harmful effect of microwaves on the human body is the thermal effect and because of this high temperature protective measures should be employed. Besides the whole body protective clothing, the use of partial shields can be considered. Protective glasses are mainly used for protection of the eyes. After people compared the metal coated glass protective glasses and the metal woven protective eyeshades, it was discovered that the protective effects of the latter were better and that its effect on vision was not very great.

The proper lowering of temperature in microwave work areas is also an effective protective measure. In order to avoid unnecessary danger, a warning sign must be made in the microwave radiation unsafe area prohibiting people from entering. The direction of antenna radiation must as far as possible avoid places where there are people.

### Section Three    Ultraviolet Rays

Ultraviolet rays include wavelengths in the spectrum range of 20-4,000 angstrom and their quantum energy is 3-130 electron volts. In their short wave band (wavelengths below 1,000 angstrom) spectrum some of the quantum energy reaches a level sufficient to cause biotissue to produce ions and therefore they can be said to be of an ion radiation character. Generally, however, some of those above the 1,000 angstrom wavelength are unable to cause the tissues to produce ions. Ultraviolet light with wavelengths above 1,000 angstrom can be

divided into three sections:

(1) Vacuum section: when the wavelength is 1,000-1,900 angstrom, they can be absorbed by air and water;

(2) Far ultraviolet section: when the wavelength is 1,900-3,000 angstrom, most can be absorbed by strong biomolecules;

(3) Near ultraviolet section: when the wavelength is 3,000-3,800 angstrom, they can be absorbed by biomolecules.

In solar electromagnetic radiation, when the wavelength of ultraviolet radiation energy is shorter than 3,000 angstrom, it only occupies about 1% of the total energy. However, most of this ultraviolet radiation is absorbed by the earth's atmosphere, especially its ozonosphere, and is able to reach the earth's surface, mainly the wavelength section greater than 2,900 angstrom. The penetration depths of the various wavelength ultraviolet rays in the earth's atmosphere as well as the strengths of ultraviolet rays at different altitudes are recorded in table 5-31. When an airship leaves the earth's atmosphere and travels towards the sun, the strength of the ultraviolet rays will be much stronger than on the earth's surface. Therefore, the effect of ultraviolet rays on the human body and protection against it must be discussed in aerospace medical science.

(see next page for table 5-31)

(太阳垂直照射, 晴朗天气, 波长2200~4000埃的紫外线辐射总量)

1 高度(公里)	2 大气透明度(相对于紫外线) ● F.N.	3 紫外线辐射强度(瓦/米 <sup>2</sup> )
0	0.429	54
3	0.515	65
6	0.592	74
9	0.654	82
12	0.705	89
15	0.738	93
18	0.763	96
22	0.800	101
25	0.826	104
27	0.846	106
31	0.910	114
38	0.972	122
50	0.999	125.6 (太阳辐射中紫
4 大气外层	1.000	125.7 外线的强度)

● 指的是紫外线能够穿透大气层的程度, 例如在50公里高度处紫外线强度为太阳辐射中紫外线原有强度的0.999。而在地面上(高度为0)紫外线强度只有其原强度的0.429。

Table 5-31 Ultraviolet Ray Strengths at Different Altitudes  
(The Total Ultraviolet Ray Radiation Wavelength  
of Solar Vertical Irradiation in Clear Weather  
is 2,200-4,000 Angstrom)

1. Altitude (kilometers)
2. Atmosphere transparency (relative to ultraviolet rays)
3. Ultraviolet ray radiation strength (watts/meter<sup>2</sup>)
4. Outer layer of atmosphere
5. (Strength of ultraviolet rays in solar radiation)
6. F.N. Indicates the level ultraviolet rays can penetrate the atmosphere. For example, the strength of ultraviolet rays at an altitude of 50 kilometers is 0.999 of the ultraviolet ray's original strength in solar radiation. However, ultraviolet ray strength on the earth's surface (altitude is 0) only has 0.429 of its original strength

#### 1. The Biochemical Effects of Ultraviolet Rays

Some of the ultraviolet rays with wavelengths shorter than 1,000 angstrom can produce ion effects on biotissues. Most ultraviolet rays in the wavelength spectrum longer than 1,000 angstrom cannot cause ionization in the biotissues yet they can cause photochemical reactions in the biotissues. The biological effects

of ultraviolet rays with wavelengths shorter than 1,800 angstrom are the strongest. For example, ultraviolet rays with wavelengths of 1,300 angstrom can destroy organic compounds and water molecules and thus form the  $\text{-OH-CN-NH}_2$  group. However, most of these types of ultraviolet rays are absorbed by the oxygen in the earth's atmosphere and rarely reach the earth's surface. 1,800-4,000 angstrom ultraviolet rays also have relatively noticeable biological effects. Photochemical effects occupy a dominant position in ultraviolet ray biological effects. Photochemical effects include the following several types: latin letters are used as symbols for the substances and their separate, combined and displacement forms are indicated in the following formulas.

- (1) Isomer  $\text{AB}^*=\text{BA}$  (\*indicate molecular excitation)
- (2) Chemical combination  $\text{AB}^*+\text{C}=\text{ABC}$
- (3) Replacement  $\text{AB}^*+\text{C}=\text{AC}+\text{B}$
- (4) Decomposition  $\text{AB}^*=\text{A}+\text{B}$
- (5) Sensitization (excited)  $\text{AB}^*+\text{C}=\text{AB}+\text{C}^*$
- (6) Polymerization  $\text{AB}+\text{AB}=\text{ABAB}$  etc.

Ultraviolet ray irradiation has living substances which cause the two types of effects of photolysis and metamorphosis: 2,800-3,020 angstrom ultraviolet rays cause photolysis and 2,537-2,600 angstrom ultraviolet rays cause metamorphosis.

## 2. The Effects of Ultraviolet Rays on the Skin

When the penetration force of ultraviolet rays is not strong, their harmful effect is limited to the eyes and skin. When ultraviolet ray energy wavelength is less than 2,900 angstrom there is complete penetration of human skin. Less than



10% of 2,900-3,200 angstrom ultraviolet rays can penetrate into the derma. Less than 50% of ultraviolet rays with wavelengths less than 4,000 angstrom can penetrate into the derma. See table 5-32 for the relation of ultraviolet wavelengths and their penetration depths.

2 可透过的 能量 (%)		3 光波波长 (埃)		4360	4050	3660	3340	3130	3020	1970	289
1 皮肤 厚度 (毫米)	0.1	59	55	49	42	30	8	2	0.01		
	0.5	7	6	5	1.8	0.3					
	1.0	0.5	0.3	0.08	0.02	0.006					

Table 5-32 The Penetration Rates (%) of Different Wavelength Ultraviolet Rays

1. Skin thickness (millimeters)
2. Energy that can penetrate (%)
3. Light wave wavelength (angstrom)

Long term repeated irradiation of small doses of 2,900-3,100 angstrom ultraviolet rays cause human skin to produce radiation chemical reactions. The skin becomes dry, brown colored and wrinkled with no elasticity. The skin radiation chemical reaction does not cause any danger but it is a sign of advancing ultraviolet ray harm.

Acute irradiation of the skin by a large dosage of ultraviolet rays, even for several minutes, can also cause erythema. This type of erythema is mainly the result of certain light ray component thermal effects in the light source. After 2-8 hours,

erythema appears again and is accompanied by burning and stinging sensations. This is the after effect of ultraviolet acute irradiation. Ultraviolet rays only have partial effects on the skin and because of this there is serious localization. Generally, the first symptoms to appear are erythema and blisters and later there are surface necrosis and shedding of skin.

Pleura and back skin are the most sensitive to ultraviolet rays, next are the forehead, shoulders and buttocks and lastly are the soles of the feet and backs of the hands. After 10-12 hours to 3-4 days of continuous burning sun exposure, the skin can turn brown, begin to peel off and afterwards the skin turns black (burned black). Ultraviolet ray harm is initially limited to the epidermis (0.05 millimeters) and cuticles (0.03 millimeters). The epidermis has a certain protective effect for the organism. The shorter the ultraviolet ray wavelength the stronger the absorption of the epidermis. This causes the organism's deep tissues to be little effected signifying the protective effect of the epidermis.

The erythema effect of ultraviolet rays is closely related to nerve conditions. Sleep, fatigue, pain and mental disorders all have an inhibitory effect on the ultraviolet ray erythema effect. However, when an animal's cerebrum is excised, during the menses of animals and humans, Jacksonian disease, pregnancy, eczema and Basedow's disease can all cause sensitivity to ultraviolet ray erythema. Skin color is also affected. The skin erythema threshold value of black skin to ultraviolet rays is over 10 times greater than for white skin.

The skin erythema effects of different wavelength ultraviolet rays are different. Charts 5-27 and 5-28 show the standard curves and relatively effects curves of the ultraviolet skin erythema effects. It can be seen from chart 5-27 that single color ultraviolet B radiation can penetrate deeper into the skin than ultraviolet C and thus cause serious erythroedema.

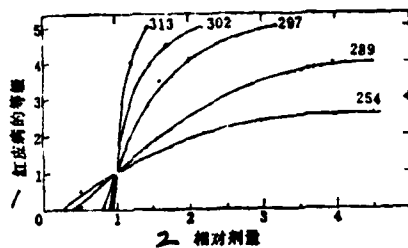


Chart 5-27 The Skin Erythema Effect of Ultraviolet Rays

The numerical values on the curves are the ultraviolet ray wavelengths (millimicrometer).

1. Level of erythroedema
2. Relative Dosage

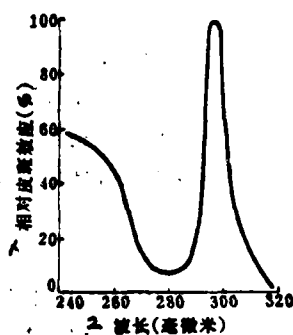


Chart 5-28 The Relation Between Ultraviolet Ray Wavelengths and Erythema Effect

1. Relative Erythema effect (%)
2. Wavelength (millimicrometers)

It can be seen from chart 5-28 that there are two peak values on the ultraviolet skin erythema effect curve; one is in the 2,800-3,200 angstrom area and the other is in the 2,500-2,600 area. This situation shows that the skin effects of long wave ultraviolet rays are somewhat different from short wave ultraviolet rays.

Individuals sensitive to ultraviolet rays can produce old age skin keratosis, epidermoid carcinoma and basal-cell epithelioma after acute or chronic ultraviolet ray irradiation. Skin cancer is a pathological effect of ultraviolet rays. Ultraviolet rays with wavelengths of 2,800-3,400 angstrom promote cancer and within this range ultraviolet rays with wavelengths

less than 3,200 angstrom can cause serious skin cancer.

### 3. The Effects of Ultraviolet Rays on the Eyes

The effects of ultraviolet rays on the eyes can be discussed from two aspects. One is relatively weak ultraviolet ray irradiation which causes a luminescent feeling in the eyes. When the surrounding environment is very bright, this type of effect is covered and not easily perceived. It causes people to lose their ability to adapt to darkness. The other aspect is when after relatively strong ultraviolet ray irradiation on the eyes harm is done to the cornea and crystalline lens.

The harmful effect of ultraviolet rays to the cornea is called photophobia ophthalmia extreme pain leukoma. Besides acute pain, tearing, excitement, conjunctiva hyperemia and ciliary muscle tics, the pathological change of the cornea is manifested in leukoma. See table 5-33 for the minimum ultraviolet ray threshold values that cause cornea harm.

1 伤害人成 动物	2 紫外线波长(埃)	3 阈值(微瓦·秒/厘米 <sup>2</sup> )	4 备 注
5 兔	2700●	19 0.05 × 10 <sup>4</sup> (尔格/厘米 <sup>2</sup> )	
6 豚鼠类	2700●	20 0.04 × 10 <sup>4</sup> (尔格/厘米 <sup>2</sup> )	
7 兔	2880	1.5 × 10 <sup>4</sup>	23 据波长2537埃的阈值和兔子相对效应的材料算出(2537埃的紫外线为常用的消毒灯的紫外线波长)
8 人	2880●	0.3 × 10 <sup>4</sup>	
9 人	2537	21 1 × 10 <sup>4</sup> (焦耳/厘米 <sup>2</sup> )	
10 人		0.15 × 10 <sup>4</sup>	24 据另一材料
11 人	2967●	2~2.5 × 10 <sup>4</sup>	25 以前未受过照射的正常皮肤阈值
12 人	2967●	5 × 10 <sup>4</sup>	26 白种人深色皮肤的阈值
13 人	2967●	8 × 10 <sup>4</sup>	27 上臂和背的一些皮肤的阈值
14 人	2500●	0.6 × 10 <sup>4</sup>	28 面部皮肤(皮肤对紫外线最敏感的部分)的阈值
15 人		0.8 × 10 <sup>4</sup>	29 极短时间在一定距离内的紫外线暴露后8小时皮肤轻微发红,24小时内消失的阈值
16 人		2.5 × 3.5 × 10 <sup>4</sup>	30 以前曾被紫外线照射过的皮肤阈值

31 F.N. 最大效应波表。

Table 5-33

Table 5-33 The Minimum Ultraviolet Ray Threshold Values  
Causing Cornea Harm and Skin Erythema

1. Harm
2. Corneitis
3. Skin erythema
4. Human or animal
5. Rabbit
6. Primate
7. Rabbit
8. Human
9. Human
10. Human
11. Human
12. Human
13. Human
14. Human
15. Human
16. Human
17. Ultraviolet wavelength (angstrom)
18. Threshold value (microwatts.seconds/centimeter<sup>2</sup>)
19.  $0.05 \times 10^6$  (erg/centimeter<sup>2</sup>)
20.  $0.04 \times 10^4$  (erg/centimeter<sup>2</sup>)
21.  $1 \times 10^2$  (joule/centimeter<sup>2</sup>)
22. Remarks
23. Calculated according to a 2,537 angstrom wavelength threshold value and materials on the relative effect on rabbits (2,537 angstrom ultraviolet rays is the commonly used ultraviolet ray wavelength of a sterilization lamp).
24. Based on another source material
25. Normal skin threshold value prior to irradiation
26. Deep color skin threshold value of white people
27. Skin threshold values for the upper arm and back
28. Threshold value for abdominal area skin (the section of the skin most sensitive to ultraviolet rays)
29. The very short time the skin becomes slightly red 8 hours after ultraviolet ray exposure within a certain distance; in 24 hours the threshold value disappears
30. The threshold value of formerly sustained ultraviolet ray irradiation
31. F.N. Maximum effect wave table

Ultraviolet cornea harm commonly occurs after 6-12 hours of the exposure. The greater the ultraviolet ray strength, the shorter the latency period. This type of harm often occurs in

personnel who work in sea, desert and snow sunshine and do not pay attention to use protective glasses. According to histological research, ultraviolet irradiation of the cornea causes photochemical deterioration and solidification of cell protein in the cornea. Nucleoproteins are especially sensitive to ultraviolet rays in the area of 2,650 angstrom and cell protein is most sensitive to rays in the area of 2,800 angstrom. It was formerly believed that the human cornea was most sensitive to ultraviolet rays with wavelengths of 2,880 angstrom. Yet, research in recent years has shown that the cornea is even more sensitive to ultraviolet rays of 2,650-2,750 angstrom. Harm caused to the eyes by the smallest dosage has no reaction to irradiation but several hours after irradiation there is an uncomfortable reaction and corneitis of the eyes with no other visible harm. This type of very light corneitis can disappear after a certain amount of time. However, large doses of acute ultraviolet radiation not only cause cornea leukoma but can also cause crystalline lens' blurriness and cataracts. Cornea harm always appears prior to crystalline lens harm. The crystalline lens ultraviolet ray harm threshold is about 2-3 times higher than the cornea harm threshold.

Ultraviolet rays can generally only create cornea and crystalline lens harm, yet, very powerful ultraviolet rays can also create eye-ground harm. The eye-ground is most sensitive to 2,700 angstrom wavelength ultraviolet rays.

#### 4. The Beneficial Effects of Ultraviolet Rays to the Human Body

Above we described the harmful effects of ultraviolet rays to the skin and eyes, yet, on the other hand, appropriate doses of ultraviolet rays can be of benefit to strengthening the physique and maintaining health. Ultraviolet rays can speed up the healing of wounds, strengthen white blood cell phagytosis, raise the ability to resist infectious diseases, reduce oversensitive reactions, promote vitamin D synthesis and promote calcium absorption and metabolism. Ultraviolet rays also have a certain disinfectant effect which is already commonly used in sick rooms, operating rooms, hospitals and laboratories. Table 5-34 lists several major effects of ultraviolet rays; some are harmful and some are beneficial to the human body but this basically depends on the wavelength and exposure time. Appropriate wavelengths and exposure times are useful and needed for human health.

We know that because infants and children have not looked at the sun for very long they have deficiencies in vitamin D which can cause rickets; if adults have deficiencies of ultraviolet radiation, this can cause mineral metabolism obstruction and blood composition abnormalities. Ultraviolet ray irradiation is desperately needed by pregnant women. If ultraviolet irradiation becomes impossible in space navigation due to airship cabin walls and space suit shield effects, then it is necessary to provide a fixed amount of artificial ultraviolet rays in the cabin and at a fixed time directly irradiate the screened surface of the body.



I 生物效应	II 紫 外 线 辐 射 条 件
2 杀 菌	12 波长2600埃杀菌效应最大。波长向长或短的方向迁移则杀菌效率急剧下降
3 致 癌	13 在波长2000~4000埃范围有致癌效应，2900~3200埃最大
4 产生臭氧	14 与杀菌效应范围相似
5 光 感 觉	15 随化学物质的光吸收特征而变化，因此不同波长这种效应是不同的
6 皮肤色素沉着	16 波长2800~3200埃刺激黑色素形成，轻度晒黑。3000~6500埃促成黑色素
7 皮肤角质层加厚，较元变性	17 在太阳电磁辐射中为波长3000~4000埃的紫外线
8 角膜结膜炎症	18 在短波范围内效应较大，波长2880埃能量 $0.15 \times 10^{-1}$ 焦耳产生此效应 使麦角醇转化为维生素D，2490~3130埃被吸收的能量为 $9 \times 10^{-6}$ 焦耳时，麦角醇化成一个国际单位的维生素D 2967埃产生皮肤红斑最强，最低功率阈值为25毫瓦·秒/厘米 <sup>2</sup> 。长或短于此波长产生皮肤红斑的 20阈值较高
9 抗佝偻病	
10 皮肤红斑	

Table 5-34 Several Types of Biological Effects of Ultra-violet Radiation

1. Biological effect
2. Disinfecting
3. Cancer
4. Production of ozone
5. Light perception
6. Skin pigmentation
7. Thickening of cuticles and collagen denaturation
8. Cornea conjunctivitis
9. Anti-rickets
10. Skin erythema
11. Ultraviolet ray radiation condition
12. The disinfecting effect of a 2,600 angstrom wavelength is greatest. When the wavelength shifts long or short, the disinfecting efficiency drastically drops.
13. In the 2,000-4,000 angstrom wavelength range which causes cancer, the 2,900-3,200 angstrom range is greatest.
14. Similar to the disinfecting effect range
15. Changes according to the light absorption characteristics of the chemical compound and because of this, this type of effect is different at dissimilar wavelengths.
16. 2,800-3,200 angstrom wavelengths excite the formation of melanin and light tanning. 3,000-6,500 angstrom wavelengths promote the formation of melanin.
17. In solar electromagnetic radiation there are ultra-violet rays with wavelengths of 3,000-4,000 angstrom.

18. In the short wave area, the effect is relatively large and wavelengths of 2,880 angstrom energy with  $0.15 \times 10^{-1}$  joule produce this effect.
19. Causes ergosterin conversion into vitamin D; when 2,490-3,130 angstrom is absorbed by energy of  $9 \times 10^{-5}$  joule, ergosterin transforms into an international unit of vitamin D.
20. 2,967 angstrom is the strongest producer of skin erythema; the lowest power threshold value is 25 microwatts . second/centimeter<sup>2</sup>. When longer or shorter than this wavelength, there is produced a relatively high threshold value of skin erythema.

#### 5. Ultraviolet Ray Safety and Protection

Each nation formulates different safety standards for ultraviolet rays and within one nation there are discrepancies in proposed standards for a certain period. Table 5-35 are the published safety standards of various nations during different periods.

Ultraviolet rays are generally not able to penetrate glass, photo materials and thicker clothing and thus protection is not difficult. Generally, both the outer shell of airships and space-suits are effective protection. Protective glasses and face guards are mainly used to protect the eyes. Because ultraviolet rays do not easily penetrate glass, the manufacture of protective lenses is not difficult. The use of medical detergents for rinsing is also effective for protection.

See next page for Table 5-35

1 材料来源 (括号内 为文献报导的年份)	2 紫外线波长 (埃)	3 安全限度	4 备 注
1. (1948)	2537	4 $1.2 \times 10^3$ (微瓦·秒/厘米 <sup>2</sup> ·天) 或 0.5 (微瓦/厘米 <sup>2</sup> )	13 眼每天7小时暴露
2. (1948)	2537	5 $0.9 \times 10^3$ (微瓦·秒/厘米 <sup>2</sup> ·天) 或 0.1 (微瓦/厘米 <sup>2</sup> )	14 眼每天24小时暴露
3. (1971)	3200~4000	6 0.1 (瓦/厘米 <sup>2</sup> )	15 加于无防护的皮肤和眼上的总辐射值
4. (1971)	2000	7 100 (毫焦耳/厘米 <sup>2</sup> )	16 加于无防护的皮肤和眼上的总辐射暴露值
5. (1971)	3150	8 1000 (毫焦耳/厘米 <sup>2</sup> )	17 加于无防护的皮肤和眼上的总辐射暴露值
6. (1973)		9 10~100 (毫瓦/厘米 <sup>2</sup> )	18 皮肤职业性暴露的安全限度
7. (1973)		10 1 (毫瓦/厘米 <sup>2</sup> )	19 暴露时间大于1000秒
		11 1 (焦耳/厘米 <sup>2</sup> )	20 暴露时间短于1000秒

Table 5-35 Safety Limit of Occupational Exposure of the Eyes and Skin to Ultraviolet Rays

1. Source of material (the year reported is in brackets)
  2. Ultraviolet ray wavelength (angstrom)
  3. Safety limit
  4.  $1.2 \times 10^3$  (microwatts . seconds/centimeter<sup>2</sup> days)  
or 0.5 (microwatts/centimeter<sup>2</sup>)
  5.  $0.9 \times 10^3$  (microwatts.seconds/centimeter<sup>2</sup> days) or  
0.1 (microwatts/centimeter<sup>2</sup>)
  6. 0.1 (watts/centimeter<sup>2</sup>)
  7. 100 (millijoule/centimeter<sup>2</sup>)
  8. 1,000 (millijoule/centimeter<sup>2</sup>)
  9. 10-100 (milliwatts/centimeter<sup>2</sup>)
  10. 1 (milliwatts/centimeter<sup>2</sup>)
  11. 1 (joule/centimeter<sup>2</sup>)
  12. Remarks
  13. 7 hours exposure per day on the eyes
  14. 24 hour exposure per day on the eyes
  15. Greater than non-protection of the skin and total radiation value on the eyes
  16. Greater than non-protection of the skin and total radiation exposure value on the eyes
  17. Greater than non-protection of the skin and total radiation exposure value on the eyes
  18. Safety limit of skin occupational exposure
  19. Exposure time longer than 1,000 seconds
  20. Exposure time shorter than 1,000 seconds
- Note: The corresponding safety limits of "source materials" 1-5 are applicable in arc lamps, gas

lamps, steam lamps and fluorescent lamps but are not suitable for lasers and sunshine or people who are sensitive to ultraviolet rays. When using these, it is necessary to notice that the relative biological effects are different at different ultraviolet wavelengths. The safety limits of different wavelength ultraviolet rays should be properly regulated according to the listed numerical values.

In order to avoid ultraviolet ray deficiency illness, during long term navigation astronauts must have total body ultraviolet irradiation at fixed times and when used in a sealed ecosystem, spacecraft cabin the problem of ultraviolet ray requirements must be considered.

#### Section Four    Infrared Rays

Infrared rays indicate electromagnetic radiation with wavelengths of 7500 angstrom to  $1 \times 10^7$  angstrom; they include 3 wavebands: near infrared light with wavelengths of 7,500-30,000 angstrom, medium infrared light with wavelengths of  $3 \times 10^4$ - $3 \times 10^5$  angstrom and far infrared light with wavelengths of  $3 \times 10^5$ - $1 \times 10^7$  angstrom. The quantum energy of infrared rays is only about 1.5 electron volts and therefore cannot cause a photochemical reaction in the biotissues and cannot even bring about material ionization. Its action is mainly the thermal effect. What we commonly call thermal radiation is actually infrared ray radiation.

The effect of thermal radiation and protective measures against it have already been detailed above in the chapter on high temperatures. Here we will only introduce the possible

skin and eye harm produced by an infrared device. Because the use of infrared rays has been daily increasing in recent years in military affairs, aviation, satellites, spaceships and surveying technology the problem of its harm and protection against it has been given more and more attention and it has become a major problem in aerospace medical science.

#### 1. The Effect of Infrared Rays on the Skin

The biological effects of infrared rays are mainly thermal effects which is equivalent to burns under high temperatures. The energy of infrared rays with wavelengths greater than 15000 angstrom can be completely absorbed by water. Bio-tissues are full with fluid and thus infrared rays very easily bring on temperature rises which cause protein solidification harm. Infrared rays with wavelengths longer than 15,000 angstrom can be totally absorbed by the skin's surface and therefore it causes skin and eye burning or total body temperature rises which form typical high temperature reactions. Infrared rays with wavelengths shorter than 15000 angstrom possess a certain permeating force. The maximum permeating force wavelength is in the area of 11,000 angstrom. About 20% of the infrared ray energy of this wave band can penetrate the skin's cuticles reaching 5 millimeters into the derma area. This creates partial blood vessel diastole thus causing the skin to fill with blood and become red.

The heat receptors distributed on the skin's surface are relatively sensitive to infrared radiation; when the skin

is within a temperature range of  $32-37^{\circ}\text{C}$  has an ascending rate of  $0.001-0.002^{\circ}\text{C}$ , this can cause threshold heat sensations. The strength of heat sensations changes in accordance with the area strength and temperature change rates of skin heating; the skin's absolute temperature only causes secondary effects. When radiation strength is further raised and exposure time is lengthened the strength of the heat sensation increases. When the skin temperature rises to above  $46^{\circ}\text{C}$ , this causes burning pain and a scalding sensation. See chart 5-29 for the infrared ray irradiation threshold values which cause skin burning pain. If radiation strength is further raised, this causes skin burns.

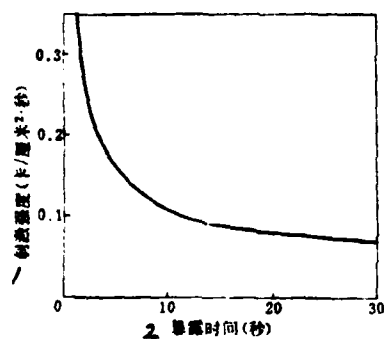


Chart 5-29 The Skin Burning Pain Threshold Value of Infrared Rays

1. Excitation strength (calories/centimeter<sup>2</sup>.seconds)
2. Exposure time (seconds)

The skin burn threshold value is influenced by the following factors:

The threshold value of the burn's blackened skin, temperature rise at 5.6 watts.second/centimeter<sup>2</sup> infrared ray

strength is  $56^{\circ}\text{C}$  after 0.5 seconds of irradiation; and in infrared ray strength of  $13 \text{ watts second/centimeter}^2$ , after 100 seconds it is  $55^{\circ}\text{C}$ .

The degree of endurance of human skin to infrared ray radiation is related to the localized and irradiated areas of the skin. For example, the endurance strength of a  $3.5 \text{ centimeter}^2$  area of forehead skin is below  $0.07\text{-}0.09 \text{ calories/centimeter}^2$  of infrared long term irradiation but a  $144 \text{ centimeter}^2$  area of upper abdomen and scapula skin can only sustain short wave infrared rays of under  $0.04 \text{ calories/centimeter}^2$  seconds.

## 2. The Effects of Infrared Rays on the Eyes

The penetration rate of  $7,500\text{-}13,000$  angstrom wavelength infrared rays is very high for the cornea and harm can be done to the eyeground. Infrared rays in the area of  $11,000$  angstrom will not cause harm to the cornea and crystalline lens but can directly create eyeground retina burns. Infrared rays with wavelengths above  $19,000$  angstrom are completely absorbed by the cornea and their effect can cause cornea blurring which is often limited to the cornea's surface layer. The thermal effect of infrared rays is related to the energy absorption rate of various tissues. The penetration rate of the cornea by infrared rays of  $7,500\text{-}13,000$  angstrom is relatively high and the absorption rate is relatively small. Therefore, the cornea harm threshold value of infrared rays in this wavelength is relatively high. Infrared rays of  $8,800\text{-}11,000$  angstrom cause the cornea harm threshold value to be  $7.5 \text{ watts second/centimeter}^2$  but the

cornea harm threshold value of infrared rays with wavelengths of 12,000-17,000 angstrom is only 2.8 watts.second/centimeter<sup>2</sup>. In daylight, the cornea sustains an infrared irradiation harm threshold value of 1 milliwatt/centimeter<sup>2</sup> (long time exposure). The major manifestations of infrared ray cornea harm are connective tissue blurriness and the formation of cornea leukoma which affects vision. When cornea temperature reaches over 47°C, this can cause pain and therefore, infrared ray cornea harm is commonly accompanied by acute pains.

The iris is a type of colored tissue which can absorb all of the infrared ray energy. This signifies that the iris has a certain sensitivity to infrared rays. However, the greater portion of infrared ray energy with wavelengths greater than 14,000 angstrom will have already been absorbed by the cornea and fluid and thus will not penetrate the iris. Therefore, there is not much danger to the iris. Because the penetration rate of the cornea and fluid is relatively high for infrared rays below 13,000 angstrom there is danger to the iris. In considering the negative aspect, iris heat dispersion capability is much smaller than for the cornea so that the same amount of heat absorption can cause harm to the iris to be more serious than to the cornea. The direct increase of iris thermal radiation strength exceeding 4.2 watts-second/centimeter<sup>2</sup> can cause harm to the iris. In relation to infrared rays of 8,000-11,000 angstrom, this type of dosage is equal to a cornea incident power density of 10.8 watts-second/centimeter<sup>2</sup>. An 8,000-11,000 angstrom infrared ray produces an iris' minimal harm cornea incident strength threshold value.



It was known early that infrared rays produce cataracts. For example occupational cataracts of glassblowers are due to infrared ray harm. This type of cataract is different from old age type cataracts. It appears as blurriness in the posterior surface of the crystalline lens and is accompanied by sheet layer cracking of the crystalline lens anterior membrane. It was proved that not all of the glassblowers and steel rolling workers had cataracts within a certain period; the greatest possibility is that there was more blurriness appearing on the posterior membranes of these peoples' crystalline lenses than for most people. Blurriness starts in the crystalline lens' posterior membrane and usually develops towards the posterior cortex. To sum up, glass and steel workers exposed to  $0.08-0.4 \text{ watts/centimeter}^2$  infrared rays for 10-15 years have a greater possibility of manifesting crystalline lens' blurriness.

The crystalline lens is located in the eye, does not have any blood circulation and only has body fluid permeation and distribution. Therefore, thermal dispersion is extremely slow and it is easy for the accumulated heat to raise the temperature. On the other hand, most of the infrared rays with wavelengths greater than 13,000 angstrom will have already been absorbed by the cornea, fluid and iris. Furthermore, when it does not reach or only a small dosage reaches the crystalline lens, the penetration rate of infrared rays with wavelengths smaller than 13,000 angstrom is very large in the crystalline lens and thus not much energy is actually absorbed by the crystalline lens. In view of this, the anterior and middle part of the eye's tissue has a

shielding effect for the crystalline lens against infrared rays. Unfortunately, the heat dispersion of the crystalline lens is slow and as soon as the iris and fluid are heated to a certain level by the infrared rays the thermal energy can be spread and transmitted to the crystalline lens which causes it to be blurry.

The cataracts created by the infrared rays also bring about the danger of glaucoma. However, this is conjecture, but naturally is rational conjecture. Investigations of glassblower cataract patients showed that many people had crystalline lens membrane peeling. If the peeled membrane blocks the Stentonian duct, vestibular fluid circulation is impeded, pressure in the eyes rises and glaucoma develops.

The occurrence rate of cataracts caused by infrared rays is related to age. This is because the penetration rate of crystalline lens nuclei for infrared rays with wavelengths under 25,000 angstrom change in accordance with age. The higher the age, the higher the crystalline lens nuclei absorption rate and the lower the penetration rate for infrared rays with wavelengths below 25,000 angstrom. Infrared rays with wavelengths longer than 27,000 angstrom cannot penetrate the crystalline lens.

Retina absorption of very short wavelength infrared rays (7,500-13,000 angstrom) is very strong and it's harm mechanism is similar to that of visible light. The retina's uvea absorbs the energy and transmits it to an adjacent area. When the retina's harm threshold is 20-40 watts/centimeter<sup>2</sup> radiation and exposure time is 0.1 seconds, this can produce harm with a diameter of 1 millimeter. The harm threshold value of the retina

yellow spot area is lower than outside the yellow spot area. Because retina harm can be produced within a fraction of a second it can create harm prior to producing pain. Fortunately, there are the light reflexes of the eyelids and pupils which in an instant block the light from entering the eyes. Therefore, there are a very few cases of infrared ray harm to the retina.

The major protective method employed for infrared ray harm to the eyes is protective glasses. High temperature protective methods should be used for infrared ray harm to other places.

There are still not enough materials on the problem of safety standards for infrared rays. Based on some investigative reports, incidents of acute harm to the eyes caused by industrial red-hot substances are not rare. Further analysis has shown that the minimum cornea incident dosage causing eye harm is about 4-8 watts-second/centimeter<sup>2</sup>. The maximum allowable dosage of whole body irradiation of infrared rays is considered to be 0.4-0.8 watts-second/centimeter<sup>2</sup>. Yet, when this strength infrared ray irradiates the eye, protective glasses must be used. According to materials on the threshold value of infrared ray cornea harm, it can be considered that the safety limit of long time infrared ray irradiation of the eyes is 10 milliwatts/centimeter<sup>2</sup> and the safety limit of one time of several minutes of acute irradiation should be 100 milliwatts/centimeter<sup>2</sup>.

#### Section Five    Atmospheric Ions

The ion density in the normal atmosphere is 100-2,000 ion-pairs/centimeter<sup>3</sup> and there are more positive ions than negative

ions. Each minute the human body takes in 500-2,000 ion-pairs. The ion density in the atmosphere changes according to the weather and difference of location. Generally speaking, in the early morning after a thunderstorm the number of negative ions of a nearby waterfall is greater; yet in places crowded with people and areas where the air is polluted there are more positive ions; the number of positive ions near atomic energy plants and high voltage equipment is higher than in most places. Because of the use of sealed environments and the effects of ionization radiation in high altitude flights and space navigation the number of atmospheric ions in the airship's cabin drastically increases. Because of this, the problem of the effect of atmospheric ions on humans necessarily becomes a problem for aerospace medical science. When an airship uses nuclear power, this becomes an outstanding problem. Using a nuclear submarine as an example, after a long period of underwater navigation, the density of positive ions in the cabin can be 10 times that of a normal submarine. This type of high density atmosphere of positive ions can cause mental fatigue, work ability to drop and some respiration tract reactions. In order to guarantee safety and comfort in high altitude flights and space navigation, the atmospheric ion density in aircraft and airship cabins becomes a problem necessitating attention.

Atmospheric ions are different sized molecular groups and they carry a positive or negative electric charge. Atmospheric ions can be divided into 3 categories based on their size and speed. F.N.<sup>1</sup> The size and speed of atmospheric ions use

the rate of shift for measurement, their standard is calculated by the unit of centimeter/seconds·volts·centimeters, which is the distance (centimeters) moved each second in a standard electric field of each centimeter·volt.

#### 1. Small Ions

3-12 molecules. The shift rate is in the range of 1-2 centimeters/second·volts·centimeters, the diameter is about  $5 \times 10^{-8}$  centimeters and the time is approximately 2 minutes. They continuously combine and separate with the molecules. The shift rate of small negative ions is 30% higher than small positive ions. The activity of small ions is great and therefore biological effects are relatively great. Small ions are commonly single pole electric charges. Their static electric energy is equal to 1.4 electron volts or  $2.3 \times 10^{-12}$  erg. They also have chemical energy. The total energy of the chemical energy and static electric energy is 6 electron volts or  $10^{-11}$  erg.

#### 2. Medium Ions

$10^2$ - $10^3$  molecules. The shift rate is in the range of 0.01-1 centimeter/second·volt·centimeter. The size of this type of ion is relatively stable and is "non-hygroscopic".

#### 3. Large Ions

$10^3$ - $10^6$  molecules. The shift rate is slower than 0.01 centimeters/second·volts·centimeters. They commonly have a "hygroscopic" core rod, are surrounded by water molecules, carry a single electrical charge and their diameters reach to  $5 \times 10^{-6}$  centimeters. They have relatively great penetrability of the upper respiratory tract.

The biological effects of atmospheric ions are related to temperature, airflow speed, the microdust density in the atmosphere and whether or not the ions are directly absorbed.

#### 1. The Biological Effects of Atmospheric Ions

The biological effects of atmospheric ions are listed within the following fields:

##### 1. Effect on Growth Rate

Negative ion air can cause the growth of a small chicken to accelerate and the growth of some field mice organs to accelerate. This type of air can also promote the growth of cucumbers, corn and oats. Positive ions do not have this effect. The effects on humans are unknown.

##### 2. Respiratory Tract Stimulation

Clinical materials show that increases of ion density to a certain level can produce respiratory tract stimulation, asthma and respiratory discomfort. When the human body is irradiated with positive and negative ions for 10 minutes respiratory tract stimulation occurs. Most people exposed to ion air for 30 minutes have upper respiratory tract and mucous membrane dry reactions. The breathing of ion air for 5-10 minutes causes the respiration quantity to drop about 30%. Negative ion irradiation can cause the fiber movement rates in the upper respiratory tracts of mice and rabbits to rise whereas positive ion irradiation causes it to lower.

##### 3. Sterilizing Effect

Positive ions all have a sterilizing effect. Beginning from

a strength of 500 microcoulomb/centimeter<sup>2</sup>, the death rate of bacteria rises drastically; when the strength is 1,600 microcoulomb/centimeter<sup>2</sup>, only about 5% of the bacteria survive. Ions also have an inhibitory effect on bacterial growth but certain suspended fluids which protect the bacteria must be eliminated.

#### 4. Effect on Blood Pressure

When in high density negative ion air for 30-60 minutes, human blood pressure falls 5-15 millimeters on the mercury column. Clinical materials provide the following data: after 30 high blood pressure patients underwent negative ion treatment, the average arterial blood pressure of 29 of the people dropped 39 millimeters on the mercury column. On the contrary, positive ions caused blood pressure to rise.

#### 5. Digestion and Metabolism

Negative ion air can strengthen human secretion activity but positive ion air can weaken secretion functions. Other ion air causes the human metabolism rate to rise.

#### 6. Effects on the Electroencephalogram

After 30 minutes of ion irradiation, the  $\alpha$  rhythm of some peoples electroencephalograms lowers; the  $\alpha$  index of other people rises and the amplitude increases; some people have rises in their  $\theta$  index. These contradictory phenomena have still not been rationally explained.

#### 7. Adrenal Gland Activity

When an animal lives in a negative ion air environment for a long time, the weight of their adrenal gland increases; the weight of animals' adrenal gland lightens when living in

positive ion air. For the most part, the effects of positive ions coordinate with the glucose-adrenal cortex element and the negative ion effect is similar to the mineral adrenal cortex element.

#### 8. The Effects of Clinical Treatment

Negative ions can cause hay fever, arthritis, pollenosis, rheumatism, burning pains and respiration difficulty and temporary or long term improvement or elimination can be attained.

Negative ions have certain advantages for the treatment of cerebral hypophysis illness, mesencephalon illness, migraines and general fatigue. Some people have boldly proposed a very immature theory that negative ions can inhibit the growth and shift of cancer and weaken the shock of losing blood.

It can also be seen in the references that ions affect the activities of certain enzymes, affect autonomic nerve activity, affect thyroid gland secretion and affect the pulse rate and electrocardiogram. Yet, many of the results have not been proven to satisfaction. Generally speaking, negative ions can play a beneficial role in human health but positive ions possibly have disadvantageous effects. There is still a lack of materials to explain this.

## 2. The Effects of Atmospheric Ions on Human Perception and Activities

### 1. The General Perception of Atmospheric Ions

Positive ions generally bring about perceptions of discomfort such as headaches, stuffed nose, itchy nose, hoarseness, dry



throat, dizziness, fatigue, drowsiness, nausea and weakness. Negative ions, however, cause people to feel comfortable, excited, clearheaded and they raise work efficiency. When exposed to 2000/centimeter<sup>3</sup> negative ions for 20 minutes, sometimes the subject feels his nose is dry, his nose has sharp pains, has eye pains and his throat is full of blood but the degree is lighter than positive ion exposure. It can be seen from this that negative ion air can be perceived by most people, only positive ion air cannot.

## 2. Effects on Sensations

Ions can affect the flash critical fusion frequency, cause central vision myctinasty and cause visual purple recovery to have wave motion. Atmospheric ions are also related to tinnitus.

## 3. Reaction Time

Negative ion air can cause reaction time to shorten while positive ions can cause reaction time to lengthen.

## 4. Effects on General Movement Abilities

Negative ions can raise movement abilities. For example, when an athlete breathes negative ion air for 15 minutes each day, after 25 days, his maintained standard value time for gripping is extended 46%. When negative ion air is breathed 25 minutes per day, after 9 days, his endurance time for exercise on a bicycle is extended 60%.

## CHAPTER Twenty-One

### VISUAL PROBLEMS IN AVIATION AND SPACE NAVIGATION

#### Section One    Preface

Vision depends on the stimulation of visible light for realization and visible light is a type of electromagnetic radiation. The wavelength of visible light is 3,800-7,500 angstrom and photon energy lies in the range of 3.1-16.5 electron volts. Chart 5-30 shows the place occupied by visible light in electromagnetic radiation. After a person enters a high altitude or outer space, there appears many differences between the visual environment and the situation on the earth's surface thus presenting aerospace medical science with many special visual problems.

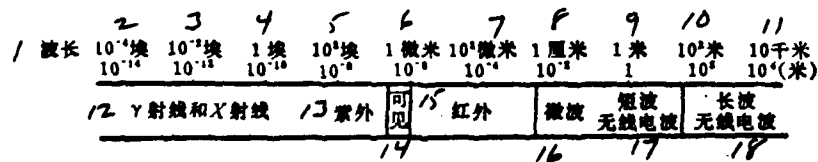


Chart 5-30 Schematic Chart of Electromagnetic Radiation

1. Wavelength
2.  $10^{-14}$  angstrom
3.  $10^{-13}$  angstrom
4. 1 angstrom
5.  $10^2$  angstrom

6. 1 micrometer
7.  $10^2$  micrometer
8. 1 centimeter
9. 1 meter
10.  $10^2$  meters
11. 10 kilometers
12. Y ray and x ray
13. Ultraviolet
14. Visible
15. Infrared
16. Microwave
17. Short wave radio wave
18. Long wave radio wave

## Section Two    Brightness - Darkness Contrast and Intense Light Vision

### 1. Brightness-Darkness Contrast and Adaptation to Darkness

Generally, the background brightness received by the human eye under normal sunlight on the earth's surface is 4,200 millilambert. Because of the earth atmosphere's scattering and reflection effect on light rays, the brightness-darkness contrast is not very outstanding. High altitude air is very thin and the brightness-darkness contrast then noticeably increases. Because there is no air moisture and dust in outer space and there are no light covering, scattering or reflection effects the intensity of sunlight increases so that in the sky and places that do not have direct sunlight, light intensity drops tremendously. In this situation, the brightness-darkness contrast is very striking. For example, at an altitude of 3-30 kilometers, the sunlight intensity increases from 11,800 foot-watts to 13,500 foot-watts, in outer space it increases to 13,600 foot-watts or 147,000 lux. Sky brightness, on the other hand, falls from 500 millilambert to 10 millilambert and the brightness of places without the shadow

of sunlight radiation is even lower. The numbers in table 5-36 show this problem.

1 高度(公里)	3 空气的视觉透明度 (全透明:1.0)	4 太阳照度	
		5 英尺-烛	6 勒
0	0.853	10834	116574
3	0.890	11277	121341
6	0.917	11648	125332
9	0.938	11908	128130
12	0.952	12091	130089
15	0.961	12211	131390
18	0.967	12285	132186
20	0.970	12318	132542
40	0.9996	12695	136599
50	0.9999	12699	136641
60	0.9999	12700	136652
2 大气外层	1.0000	12700	136652

Table 5-36 Direct Solar Brightness in Clear Air

1. Altitude (kilometers)
2. Outer layer of the atmosphere
3. Visual transparency of air (total transparency: 1.0)
4. Solar brightness
5. Feet-watts
6. Lux

In this type of situation, the brightness contrast can reach to over 60,000:1. At this time, it is only necessary for the airship to change several degrees and within several seconds the cabin brightness can descend from  $10^4$  millilambert to  $10^{-6}$  millilambert. If it is necessary for the eyes to go from a sunlight to a dark area then it is very difficult to adapt to darkness and this causes temporary inability to see the instruments and control equipment clearly. The occurrence of this type of phenomenon possibly creates control errors and thus cannot be ignored.

Human night vision is better during the winter than during the summer. The vision non-adaptation caused by sudden changes in summer brightness is possibly more serious than in winter.

Because high altitude air is very thin, air scattering and refraction are greatly weakened, sky illumination, earth surface brightness and sky tone accordingly change. Tables 5-37 to 5-39 show this situation.

1 高度(公里)	2 太阳明度(毫朗)	3 太阳明度(焦/米 <sup>2</sup> )
3	470	1496
6	320	1018
9	210	668
12	140	448
15	82	261
18	50	159
22	30	95
25	19	60
27	12.5	40
31	6.8	22
38	6.2	20
50	6.0	19
100	4.0	18

Table 5-37 Maximum Brightness at Different Altitudes (Solar Angle of Elevation 60°)

1. Altitude (kilometers)
2. Solar brightness (millilambert)
3. Solar brightness (watts/meter<sup>2</sup>)

See next page for Table 5-38

1 太阳仰角(度)	2 天顶明度(英尺-烛)	3 地面明度(英尺-烛)
10	1080	4300
30	4780	7830
50	8060	6950
70	10250	4250
90	11050	6.5

Table 5-38 The Earth's Surface and Maximum Brightness

1. Solar angle of elevation (degrees)
2. Maximum brightness (feet-watts)
3. Earth surface brightness (feet-watts)

表5-39 高空天空色调变化

1 高 度	2 天空的色调	3 周围现象
4 约16公里上空	10 蓝	16 水中核爆炸的蘑菇云的上缘高度约40公里
5 约32公里上空	11 蓝黑	
6 约48公里上空	12 深蓝	17 夜光云的高度约80公里
7 约89公里上空	13 深蓝黑	
8 约145公里上空	14 黑	18 流星的高度约120公里
9 >145公里	15 黑	

Table 5-39. High Altitude Sky Tone Changes

1. Altitude
2. Sky tone
3. Surrounding objects
4. About 16 kilometers
5. About 32 kilometers
6. About 48 kilometers
7. About 89 kilometers
8. About 145 kilometers
9. > 145 kilometers
10. Blue
11. Blue-black
12. Deep blue
13. Deep blue-black
14. Black
15. Black
16. Upper edge altitude of a mushroom cloud of an atomic explosion set off in water is about 40 kilometers
17. The altitude of a noctilucent cloud is about 80 kilometers

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18. The altitude of a shooting star is about 129 kilometers

If space navigation is from the earth's surface towards the sun, the closer to the sun, the greater the sunlight intensity. On the contrary, if the sun is behind the ship, the further from the sun the weaker the sunlight intensity. In order to prevent the excessively strong sunlight in the former mentioned situation from harming the eyes protective measures such as wearing sunlight protective glass must be adopted. On the other hand, in the latter mentioned situation, suitable artificial lighting must be adopted in order to see objects clearly. When the airship's distance from the sun is more than 10 times the distance from the sun to Pluto, the airship seems to enter a dark world totally devoid of color. At this time, if the airship cabin does not have any artificial light then there are no means to live and work.

With solar radiation strength, besides the distance determined from the sun the shadows of celestial bodies also have a certain effect. It can be seen from this that the special realities confronting space navigation are visual problems caused by very strong and very weak light rays which medical science cannot avoid.

### 3. Strong Light Causing Blindness, Flashing Light Causing Blindness and High Altitude Subjective Fog

Because the sunlight in outer space has no air, its strength is weakened much more than on earth. For example, when

a satellite uses a light reflecting aluminum outer shell, if the reflection rate is 0.55, solar brightness can reach 7,000 feet-watts. Under stronglight illumination brightness exceeds 1,000 feet-watts and when the eyes are opened to observe objects they feel stimulated and uncomfortable. If the surrounding brightness-darkness contrast is very large, this discomfort can become even more intense. This is very disadvantageous to visual work efficiency. Chart 5-31 shows this type of phenomenon. The curves in the chart show the relationship of vision power, background brightness, target and degree of background contrast; when the degree of contrast is high, vision is good but when it is not, vision is poor.

Very strong visible light can cause retina burns. However, blinking and iris reflexes can avoid or decrease this type of harm. So-called eclipse blindness or blindness caused by strong light is this type of retina burn phenomenon and it was earliest seen in people who observed eclipses with the naked eye. Its major symptom is a permanent blind spot in the field of vision. The critical time for creating this type of harm by looking at an eclipse from the earth's surface is 1 minute or a little less. Because the strength of sunlight is about 50% higher in the upper layer of the atmosphere than on the earth's surface, this critical time shrinks to within 10 seconds for this layer and if flying towards the sun with no protective glasses, this type of visual harm will naturally be even more dangerous. In reality, people cannot endure this type of strong light and therefore must adopt effective protective measures. Chart 5-32



summarizes the critical strengths of visible light that cause retina harm. Generally speaking, when visible light strength exceeds 1 watt/centimeter<sup>2</sup> and exposure time is more than 1 second, this can cause cornea pain and at this time protection should be used.

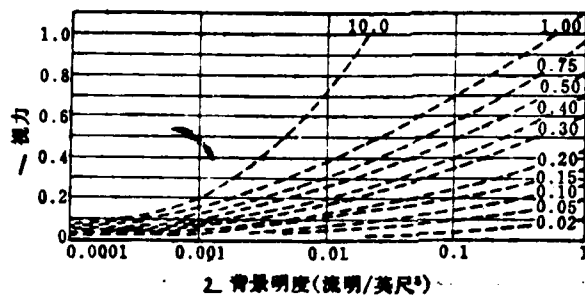


Chart 5-31 The Relationship of Vision Power to Background Brightness and Degree of Contrast

1. Vision power
2. Background brightness (lumen/feet<sup>2</sup>)

The numerical value on the curves is:

$$\text{brightness contrast degree} = \frac{\text{target brightness} - \text{background brightness}}{\text{background brightness}}$$

See next page for chart 5-32

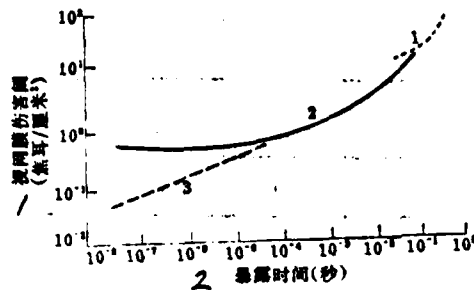


Chart 5-22 Retina Harm Threshold of Visible Light

1. Retina harm threshold (joule/centimeter<sup>2</sup>)
2. Exposure time (seconds)
- Line 1 - Diameter of visual object is 240 microns;
- Line 2 - Diameter of visual object is 700 microns;
- Line 3 - Diameter of visual object is 1,000 microns

When the strength of a strong light or strong flashing light is lower than retina burning, although retina harm has still not been created, yet sometimes this can cause visual impairment and objects cannot be seen clearly within a short period of time. This phenomenon often occurs with exposure to sudden strong flashing light. For example, the instant of an atomic bomb explosion is called flashing light blindness. If in outer space the eyes look towards a shadowy area, when after adaptation to the darkness there is sudden turning to a sun-light area, the pupils cannot contract very small in time and the pupil reflex is not complete, the strong light can partially or totally fall on the retina with results similar to facing the flash of an atomic bomb explosion. This type of

flashing light is sufficient to cause an astronaut to have visual impairment for several seconds to several tens of seconds. For example, if the strength of the flashing light is 50,000 lux and exposure time is 0.15 seconds, this can cause flashing light blindness for as long as 0.2-0.8 minutes.

Besides the two above mentioned situations, strong light can also cause other special visual phenomena such as the following:

1) Changes in color perception. Under very strong illumination an object's color seems to change. If the wavelength of a red light is 6,150 angstrom and light strength continually increases, the color appears to change from red to yellow and finally changes to green. For example, when the wavelength of a yellow light source is 5,750 angstrom and there is extreme brightness, it can change from yellow to green. This type of phenomenon is called strong light color change.

2) Perceptual changes of shape and size. Under strong light, objects appear larger than their original size. If an object occupies a 39 degree arc of the angle of vision and the lighting is 2,602 feet-lambert, the perceived size can increase the angle of vision about a 5 degree arc. Lighting of 7,897 feet-lambert can increase the angle of vision a 7-8 degree arc.

The shape of the object appears somewhat different than normal under these conditions. These phenomena signify that when a person is in a course towards the sun, extremely strong sunlight causes a person to feel that there is a discrepancy in the shape, size and color of the object as compared to under

normal lighting conditions.

The so-called high altitude subjective fog phenomenon occurs in high altitude flight especially when the oxygen supply is deficient. The pilot feels that after looking outside the cabin at the sun shining on the clouds, there seems to be a white cloud layer covering in front of his eyes so that he cannot see the instruments and control equipment in the cabin clearly. Without a doubt, this is caused by the visual after-image of the strong light of the sun shrinking on the clouds. When there is a lack of oxygen, this type of afterimage lasts several times longer than normal. High altitude subjective fog is eliminated by a sufficient supply of oxygen and by wearing sunlight protection eyeshades.

#### 4. Pencil Straight Light (Collimated Light) Vision

Outer space light rays do not have air, moisture scattering and reflection and therefore are relatively collimated.<sup>F.N.1</sup> Under these conditions, not only is the brightness-darkness contrast of part of the object's lighting and part of the shadow completely noticeable but the half shadow area commonly seen on the earth's surface is also lacking. The half shadow area is very significant for the perception and discrimination of an object's three dimensional shape and distance. When approaching pencil straight sunlight in outer space, the object appears to be somewhat unreal lacking in three dimensionality. For example, because

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F.N.1 Collimated is a physics term indicating pencil straight, unscattered light.

of the strong brightness-darkness contrast and lack of half shadow area, an airship's structure seems to be separated into two sections.

When astronauts walk on the moon's surface, the lack of a shadow area also causes them to feel that their three dimensional and depth vision is inaccurate. When they walk on a surface facing the sun and the strong sunlight penetrates their face guards and shines on their eyes, this causes visual discomfort; yet this does not basically effect their walking. On the contrary, when walking with their backs against the sun, various objects are lit up brightly and half shadow area; most objects can be seen yet not as clearly as on the earth's surface. Only if the sunlight shines from the side is it easier to discriminate the shape and size of objects. It is also possible that because objects lack a half shadow area there are shape illusions created. For example, when a spheroid is illuminated by light from one side it appears to be hemispherical but when a certain part of a cube is in the shadow it appears to be flat or trapezoidal. Besides this, under pencil straight lighting; there is a tendency to judge the size of object as being small.

Human vision control efficiency decreases when there is pencil straight lighting. For example, under lighting, the completion time for button control according to a certain numerical signal is 10-45% longer than under normal lighting and the rate of errors increases 14-50%. The effect of light rays shining from the back of a person is very small.

## 5. Scotopic Vision

When an airship flies with its back to the sun and navigates to the shadow of a celestial body scotopic vision usually occurs. The general physiology of scotopic vision is not covered in this book but below we will simply introduce several measures for raising scotopic vision.

1) The taking of vitamin A pills and foods abundant in vitamin A

2) Prior to takeoff of night flights or prior to beginning scotopic vision work, wear red colored glasses for 30 minutes.

3) Avoid strong light entering the eyes (such as searchlights and strong lights inside and outside of the cabin). Lighting inside the cabin should be as low as possible so as to guarantee the minimal work. If strong light cannot be avoided, then red colored light filter glasses should be quickly put on.

4) When observing a target one must have the target  $10^\circ$  from the central line of vision because the sensitivity of the retina's fovea centrabis to subdued light is lacking an edge of  $10^\circ$  compared to the retina. Because of this, a  $10^\circ$  visual line of deflection is beneficial to seeing targets clearly in subdued light. Night pilots should have a good deal of ground training for this type of observation method.

5) Maintain continual movement in line of vision

6) Have the visual object or target as large as possible. For example, when flying just above or just below an enemy plane, the image of the enemy plane is largest.

- 7) Keep glasses and face guard clean
- 8) Have a full supply of oxygen
- 9) Maintain physical health and as far as possible avoid effects of various bad environmental factors.
10. Undergo training in night vision, subdued light searching and subdued light observation.

### Section Three    Empty Field of Vision and Aerial Blind Areas

The meaning of the term empty field of vision is the lack of a structure or single substance in the field of vision. When flying in a cloudless clear sky, in a dark field of vision or in thick white clouds there is a strip of white in the field of vision. This is a typical case of empty field of vision producing unreal results in vision. Several major situations are given below.

#### 1. Empty Field of Vision Myopia

Under empty field of vision conditions, the human eye has difficulty focusing on boundless distances. From this there is produced the equivalent of 0.75D ( 0.5-1.0D) myopia. For this reason, a small object must be half the distance in empty field of vision than normal field of vision to be seen or the visual image must be twice the size in order to be seen.

#### 2. Empty Field of Vision Color Changes

If there are colors in the empty field of vision, then after a relatively long time of gazing the color gradually fades and finally becomes a neutral ashen or light black color. This type of phenomenon can be called empty field of vision color changes.

### 3. Visual Illusory Movements

Single or not many solid objects in an empty field of vision such as stars in a black sky or black spots (aircraft) on a white background can cause illusions of movement after gazing at them for several tens of seconds and this is called visual illusory movements. These types of illusions are often the cause of errors in astronomical observations, satellite observations and are the reason for errors in the discrimination of the movements of the lead aircraft when flying in formation. In night navigation, sometimes there can also be the perception of a stationary star as an aircraft in movement due to this type of illusion. In space flight, this type of illusion can also affect the meeting of airships in space, aerial search and the precision of visual astronomical navigation work.

### 4. Aerial Blind Areas

There is a latent period from when a person sees an object to when he reacts and this is called the reaction time. The lengths of reaction times differ in accordance with visual discrimination and the complexity of control work. Visual reaction time is at the least about 0.1-0.2 seconds. An aircraft traveling at a speed of  $1M$  ( $M$  is the speed of sound) flies about 70 meters in 0.2 seconds. An aircraft traveling at a speed of  $3M$  flies 200 meters in 0.2 seconds. If two aircraft fly toward each other at speeds of  $3M$  then the two aircraft can approach each other at a distance of 400 meters in 0.2 seconds. In other words, when two aircraft fly towards each other at speeds of  $3M$ , if the aircrafts have already approached the distance of 400 meters, the



pilots can then discover each other and after the pilot discovers the other's plane he can immediately enact his evasion controls. Yet, because reaction time is slow they cannot avoid collision. It can be seen that vision at a distance of 400 meters actually does not have any affect on the after effects of the control movements of these two aircraft. Therefore, this distance is called the aerial blind area. Because in practice control movements are complex, pilot reaction times are generally about 1-2 seconds. In this way, if an aircraft is traveling at a speed of 1M towards a stationary object (such as a high mountain), the aerial blindness area can be lengthened to 350-700 meters; if an aircraft is just coming out of clouds at this distance and sees a high mountain, if the pilot immediately inacts evasion control, the aircraft cannot avoid colliding with the mountain.

When the speed of an airship reaches over 8-11 kilometers per second and if the astronaut's visual reaction time is 1 second, the airship's aerial blindness going toward a stationary object is 8-11 kilometers. If the astronaut in the airship turns from looking outside the cabin to look at the instruments because of the drastic brightness change from outside to inside the cabin the temporarily poor adaptation by the eyes and the time needed for moving the head and eyes again, the astronaut's visual complex control reaction time often averages about 2 seconds. In this way, the airship's aerial blindness area can reach 16-22 kilometers. If we further consider the factor of empty field of vision myopia, then this distance would be twice

as large. If the aerial blindness area is 8 kilometers in aerial flight, then a 6.6x6.6 meter object has actually already fallen into the aerial blind area when they are discovered by the pilots in the empty field of vision. Based on this, when the surface area is smaller than this object, the astronaut actually has no means of using an effective visual reaction for it. The method of resolving this is the use of instruments for spotting.

#### Section Four Visual Problems of High Speed Aircraft

There are a series of visual problems in high speed aircraft. Here we are only able to summarize some of these.

##### 1. Effective Field of Vision Widths

The fovea centralis of the human eye has the highest degree of visual sensitivity, has the shortest reaction time and causes effective long distance vision for high speed flights. In aviation technical terminology, effective vision is the effective distance from the time a pilot sees an object to when he reacts without having the object collide with the aircraft. The visual sensitivity of the peripheral field of vision is relatively deficient so that when aircraft speed is increased its effective vision is gradually lost. In other words, the range of effective vision gradually shrinks in accordance with the increase of aircraft speed. This type of change relation is identical to the sensitivity of the human eye and the changes in reaction time. Based on this type of change relation we can draw an effective field of vision chart of a person in high speed flight as shown in chart 5-33. In the chart, curve 1 is the visual axis line;

curve 2 is the field of vision limit created because of visual reasons;  $M_1-M_9$  (not completely drawn in the chart) separately indicate the limits of 1-9 speed of sound flight speeds on effective vision. Curve 2 and the area encompassed by the M curves are the actual effective fields of vision during high speed flights. Yet, the effective field of vision shrinks in accordance with the increases in flight speed. Curve  $M'_1$  indicates that when flight speed is 1M, after considering the eyes focusing time and field of vision discrimination time, the effective field of vision further shrinks. Calculating according to this mutual relationship, if we take a person as the standard for effective visual discrimination reaction, then when the flight speed is 1M the effective field of vision is only 1/3 as weak as normal field of vision. When flight speed is 6M, the effective field of vision is limited to a several degree range of the fovea centralis. When flight speed is above 9M, the effective field of vision approaches zero. In this type of situation, when the object is seen clearly the aircraft is already unable to avoid colliding with it. It should be pointed out that the effective field of vision is also related to the size of the object so that the larger the object the larger the effective field of vision. Spacecraft speeds reach to over 25M and the problem of their effective field of vision is even more worthy of attention than for common aircraft.

See next page for Chart 5-33

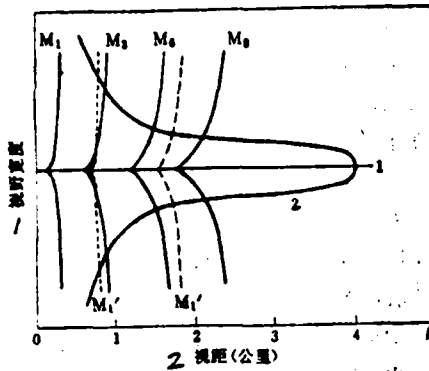


Chart 5-33 The Effective Field of Vision of High Speed Aircraft

1. Field of vision width
2. Visual distance (kilometers)

## 2. Perception of Object Movement Speed

People are affected by various factors in the perception or discrimination of object movement speed including object size, distance, brightness and movement speed. If the object is small, far away, lacking in brightness and dark in color, this will cause people to feel that its movement speed is slow, otherwise it will cause them to feel that the movement is fast. This reflects the rule of perceiving object movement speed on the earth's surface. Since the discrimination of object size, distance, color, brightness and movement direction are not sufficiently accurate for airspace and outer space, then it cannot be very accurate for the discrimination of movement speed and how much less so for aircrafts in movement. Problems related to the effects of object and aircraft or airship's movement

direction are often told to us. The two, direction and speed movement, cause people to be unable to perceive object movement. Otherwise, if the movement direction of the two is opposite then they can feel the speed acceleration of the object movement. This is a normal phenomenon; earth surface perceptions are the same, as well as airspace, and the two can be explained by the same law.

### 3. Visual Perception of Air Vibration Waves

Airship and aircraft high altitude flights cause air to produce vibration waves. At speeds below 1M this type of wave is still not large and there are no noticeable visual effects. When the speed exceeds 1M, this type of vibration wave is very large and produces visual effects similar to the visual distortion brought about by uneven transparent glass. The degree of effect is related to aircraft and airship speed as well as atmospheric density. The greater the aircraft speed, the greater the effect on vision.

### 4. The Effect of Oblique Optical Surfaces

In order to maintain aircraft and airship speed it is often necessary to make the cabin streamline with the result that porthole glass must be oblique or curved. When the glass is oblique its bent light can affect vision. This is a visual after effect directly created by high speed flight. Generally speaking, when the incline of bulletproof glass is smaller than  $70^{\circ}$  this will not cause noticeable changes in power of vision and depth perception but will only produce an incline smaller

than a 3' angle. When the glass incline is too great then a certain amount of loss (shrinkage) is sustained in the field of vision.

5. The Effects of Object Movement Speed and Direction on Visual Discrimination

When looking from the air to the earth's surface, one can sense the movement of surface objects; the faster the speed, the shorter the perception time of object shift direction. At the same time, this depends on the size of the object's displacement direction angle; when the direction angle enlarges, the shorter the time of object displacement direction discrimination.

6. The Effects of Object Motion Speed on Visual Discrimination Efficiency

When object motion speed increases, the discrimination efficiency of the object is deficient. When an aircraft goes forward at a certain speed, there are great discrepancies of the object's angles on the different angles to the left and right of the aircraft's course. The larger the included angle of the course and position occupied by the object, the larger the angular speed. Because of this, the more the object inclines towards the two sides of the course, the more difficult it is to see clearly; on the contrary, the more towards the front of the course the object is, the easier it is to discriminate.

Section Five. Problems in Aerial Observations

1. Satellite observation and aircraft search.

When observing a satellite or airship on a bright sky background from the earth's surface, its degree of visibility depends on the brightness of the satellite and the brightness of the

background. See chart 5-34 for the relation of a 99% visible threshold to object size, brightness-darkness contrast and background brightness.

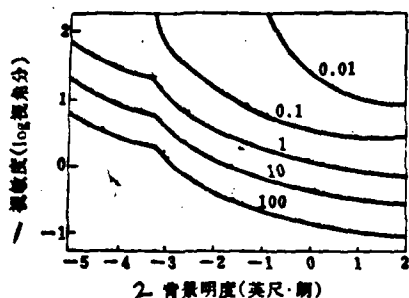


Chart 5-34 The Relation of Background Brightness, Degree of Contrast and Visual Sensitivity

(The numerical values on the curves are the degrees of brightness contrast).

1. Degree of visual sensitivity (log visual angle)
2. Background brightness (feet·lambert)

During the daytime, because the brightness of the sky background is very great, even though the satellite is in relatively bright sunlight, the brightness contrast on the sky background is often so small that it is not sufficient for people to see. At night, because the satellite is in the shadow of the earth, brightness is very weak; it is difficult for the naked eye to see clearly. Because of this, the best opportunity for visual observations of satellites is at dusk or at dawn. When the sun is  $10^{\circ}$ - $20^{\circ}$  below the horizon, the brightness of the satellite is equal to about 3.5-6.0 stars. If a telescope with a diameter larger than 5 centimeters is used, when the sun is no less than

3°-4° lower than the horizon satellites can be seen.

When observing from the earth's surface, if the satellite's position is fixed and is known beforehand then it is easy to observe. On the contrary, if the satellite's position is changing and not fixed, then it is more difficult to observe. For example, see chart 5-35 for the observation efficiency when using a telescope to observe a simulated satellite bright point. In the chart, the short lines in the bottom right corner circle indicate the possible position of the satellite in the telescope; curve a is the 98% observable brightness threshold value when the position of the satellite is fixed and known beforehand; curve b is the 98% observable brightness threshold value when the satellite is moving and its position is not fixed. It can be seen from this chart that the latter brightness threshold value is much higher than that of the former. If the appearance time of the satellite is not known beforehand and the appearance times of each satellite have very long intervals and are very irregular (for example, the interval time is greater than 30 minutes) then satellite observation will be very difficult. Sometimes the appearance and observation time is as long as 20 seconds which is still a phenomenon that cannot be observed within 15 minutes.

See chart 5-35 on next page

730



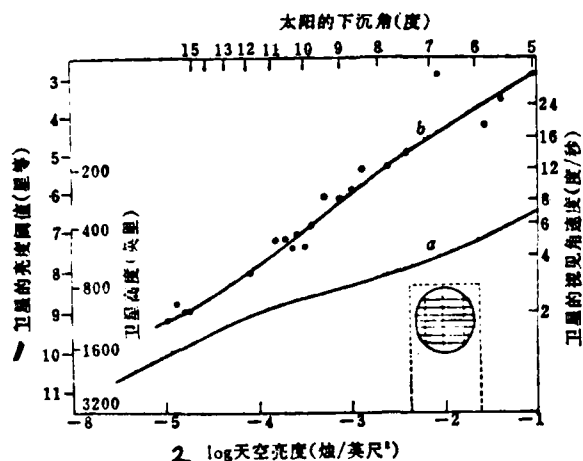


Chart 5-35 The Relationship of a Satellite's Brightness Threshold Value and Sky Background Brightness

1. Satellite brightness threshold<sub>2</sub> value (stars)
2. log sky brightness (watts/feet<sup>2</sup>)

When a satellite appears in the field of vision, it is easily observed by people. If it appears in the periphery of the field of vision, observability is much lower. One reason for difficulty in observing a satellite which appears in the periphery of the field of vision position is changing and not fixed, then it is more difficult to observe. For example, see chart 5-35 for the observation efficiency when using a telescope to observe a simulated satellite bright point. In the chart, the short lines in the bottom right corner circle indicate the possible position of the satellite in the telescope; curve a is the 98% observable brightness threshold value when the position of the satellite is fixed and known beforehand; curve b is the 98% observable brightness threshold value when the satellite is moving and its position is not fixed. It can be

seen from this chart that the latter brightness threshold value is much higher than that of the former. If the appearance time of the satellite is not known beforehand and the appearance times of each satellite have very long intervals and are very irregular (for example, the interval time is greater than 30 minutes), then satellite observation is that the various light reception areas of the human retina are different so that the closer to the periphery of the field of vision the more deficient the power of vision and brightness contrast threshold. Chart 5-36 shows this relationship.

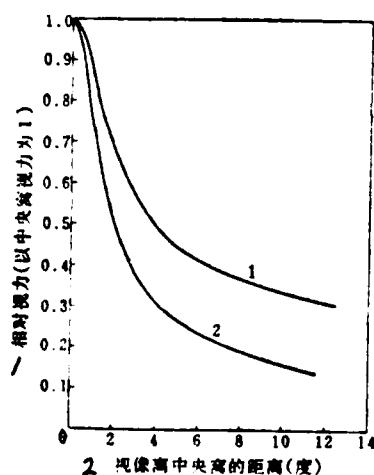


Chart 5-36 The Relative Power of Vision Curves of the Peripheral Field of Vision

1. The relative power of vision (taking the fovea centralis power of vision as 1)
  2. The distance (degrees) of the peripheral field of vision of the fovea centralis
- Line 1. Target appearance time is 1/3 second  
 Line 2. Target appearance time is 1/100 second

Besides this, when a target approaches the extreme periphery of the field of vision, the eye's locating ability is very deficient. Generally, precision locating is difficult in a  $10^\circ$  range and locating errors can often occur to the point of having false locating reactions. The observation ability of peripheral field of vision is good for moving targets, yet it is difficult to accurately distinguish a target's direction of movement. Very fast and very slow movement directions are easily mistaken. Peripheral field of vision has no color perception. Moreover, the individual differences in peripheral field of vision visual ability are very great. Therefore, generally speaking, the reliability of the peripheral field of vision is very low. Because of this, when observing satellites, it is always necessary for the observer's line of vision to continually inspect each area of the field of vision so as to increase the probability of the satellite falling in the center of the field of vision.

A type of inspection search work similar to satellite observation is airship searching. When an airship is required to meet or join in outer space as well as when searching is required after an airship returns to earth, there can be many problems in searching for the airship. The location of an airship in space and its location after returning to earth is often only generally known. Because of this, it is always necessary to undergo search to be able to discover it. Search work for airships that have returned to earth can cause great eye fatigue. For example, when the searching range of each person on the ocean surface is  $20^\circ$ - $40^\circ$  and the search time for each group is 30-60

minutes, there is a 30 minute rest afterwards. After workers are on duty their eyes can feel very tired and some people cannot see things clearly for a long time. In order to make searching more convenient, some people think that it is best for the outside shell of the airship to be painted with bright colors easily discriminated from the colors of the earth, sea and forests. Flashing light signals on the airship is also a relatively good method. Flashing lights are advantageous to peripheral vision. The brightness on the outside shell of the airship can reflect a relatively bright light when there is sunlight irradiation and this is also a method that can be adopted. When selecting colored signal lights, one problem should be considered; the efficiency of night for distance vision is different for different colored lights. Blue lights have the farthest visible distance and their brightness is most outstanding while red lights are relatively deficient. When similar brightness red lights are viewed beyond 16 kilometers, their brightness perception is only 1/1,000 that of the blue lights. Moreover, peripheral vision cannot perceive red light.

When carrying out target search, the probability of the target falling in the center of the field of vision forms an inverse ratio with the size of the search field of vision but forms a direct ratio with the size of the target body (see chart 5-37).

See next page for chart 5-37)

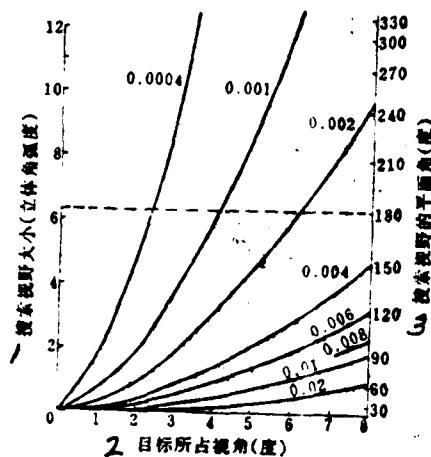


Chart 5-37 The Probability (P) of a Target Falling in the Fovea Centralis  $1^\circ$  Field of Vision Range When Searching in Space  
(The numerical values on the curves indicate probability (P)).

1. Size of the search field of vision (three dimensional angle radian)
2. Visual angle (degrees) occupied by target
3. Plane angle (degrees) of search field of vision

## 2. Visual Problems in Aerial Rendezvous Docking and Airship Soft Landing Control

In practice, airship rendezvous docking is very important. For example, when two airships are meeting, docking or joining in space it is necessary to have aerial rescue, cooperation and capture. Furthermore, if in lunar navigation the lunar capsule is carried into a lunar orbit by the master module and later launched to the moon, the master module continually orbits the moon and waits for the lunar capsule to return to the lunar orbit and rendezvous dock with it. Afterwards, they return to earth together. The rendezvous of the master module and target capsule (the lunar

capsule) commonly adopts the orbital shift mode.

The tasks of the astronaut is to carry out visual direction when the target is in the range of vision and to control the airship's rendezvous and docking. Tests done in earth simulators show that people can accomplish the control tasks of rendezvous and docking visually. In reality, astronauts had completed the tasks of rendezvous and docking many times in space using visual control. The primary problem in airship rendezvous and docking control is the searching and surveying for the target. In order for the target to be easily seen, visual rendezvous control must be carried out under solar illumination (daylight). At the same time, it is also necessary to have the best phase angle for observation. When the target is between the airship and the sun and the phase angle ( $\phi$ ) is  $180^\circ$ , observation is not good because the astronaut must face the sun. When the target is between the airship and the moon and is situated on a very bright earth horizon, this is also not advantageous for observation. The best observation conditions are when the airship is between the sun and the target so that the target is not blocked by the airship and shadow of the earth.

A black target with a diameter of 1.2 meters and a reflection rate of 10% makes an angle of  $90^\circ$  with the sun when at a distance of 21.6 kilometers and this can be seen by the naked eye. Generally, the diameters of astronomical targets are larger than 1.2 meters and their reflection rates are greater than 10%. Thus, they can be observed in space by the naked eye and visual direction can be accomplished.

Space rendezvous not only requires searching for the target but also observation and location of it. If placed in disadvantageous conditions, the errors of visual locating can be very great. For example, when the target is between the airship and the sun the astronaut must observe the target facing the sun and thus target location error can be over a 6.1 visual angular arc. Under better conditions, the target location error will undoubtedly be much smaller. The maximum permissible location error for space rendezvous visual navigation is a 10-20 second visual angular arc. Because of this, if visual location must be done facing the sun then protective eyeshades and filter lens must be used to greatly weaken the shine of the sun's light.

One part of the airship's orbit is in the earth's shadow and the percentage of orbital flight time occupied by the earth's shadow (night) changes in accordance with the orbit's altitude. When the orbit is relatively low, the proportion of time in the shadow area is very great and thus the problem of night observation of targets must be considered. On a starry sky background with a  $10^\circ$  field of vision, the discovery time of a moving object (light source) changes in accordance with the speed of the target's movement. When the target speed is 0-3.2 milliradian discovery time is generally within 4.0-2.5 seconds; the faster the target's movement, the shorter the discovery time. In order to aid the astronaut in discovering moving targets on a starry sky background, the use of a minute grill vernier added on to the airship's telescopic lens can be considered. When the target moves, it is blocked by the grill

for a while and then it leaks out (appears) in the gap thus creating a twinkle. Stationary stars cannot create this type of twinkle. This helps the astronaut to distinguish moving targets on a starry sky background.

Another problem of target location in outer space is: when the target is very bright, this can increase location errors.

Regarding the visual direction and location problems of soft landings, in order to avoid the sun shining too brightly on the surfaces of the earth and moon which make it difficult to observe ground shapes, some people think that it is best to soft land on the moon at a  $7^\circ$  and  $20^\circ$  solar altitude. Under these conditions, the moon surface depends mainly on the earth's illumination and not the sun's. The strength of solar light reflected by the earth is 50 times greater than that of the moon. Because of this, the illumination sustained by the moon is much stronger than the moonlight seen on the earth's surface at night.

Simulated tests for the minimum lighting required for lunar soft landing using the manual control method (the selected landing point and determined lunar surface approaching speed) have been carried out by people using a helicopter landing from an altitude of 300 meters. The results were: the minimum permissible earth surface brightness level was 0.04 feet-lambert; when brightness was lower it was difficult to accurately complete visual soft landing control.

When sunlight or light reflected from the earth shone directly on the surface of the moon, the moon surface ridges and other three dimensional shapes appeared very bright and dazzling.



However, if a telescope was used for observation, only when a certain angle of sunlight or earth light irradiated the moon could the shadows of the ridges be used to discriminate three dimensional shapes. When light rays shone vertically on the surface of the moon, the moon's surface appeared flat and the protrusions and hollows of the ridges were not very noticeable. Thus, the selection of a landing point for lunar visual manual control landing is not very advantageous.

The results gained from research on the problem of visual astronomical navigation based on simulated visual astronomical navigation carried out in an earth astroscope showed: using 4 known constellations as navigation targets, it was necessary to quickly find the target, constellations in the astroscope's zenithal projection so as to use vision to complete the task. The discovery time of the navigation target constellations forms a converse ratio with the size of the field of vision. When the field of vision is greater than  $30^{\circ}$ , the discovery time generally stabilizes in the range of 15-20 seconds.

SECTION SIX  
HYGIENE AND MEDICAL GUARANTEES

GENERAL REMARKS

The previous chapters mainly discussed the effects of the special conditions in aviation and space navigation on the human body and the problems of protection against them. In order to complete the tasks of space navigation, besides having to carry out the necessary protection against the various special conditions in navigation, it is also necessary to guarantee the various supplies (food, water, gases etc.) needed for life and to guarantee a close to normal living environment as well as the necessary hygiene and medical safeguards. This will be the main content of this chapter.

CHAPTER TWENTY-TWO  
SPACE NAVIGATION LIFE GUARANTEES

Section One    Human Metabolism

Each day people continually take in nutritional matter from the outside environment and after it is processed it forms needed matter for the tissues. At the same time, the old matter decomposes and forms waste material which is excreted out of the body and new metabolism takes place. Each day an individual takes in an average total weight of 3-4 kilograms of matter as well as

about 2-3 kilograms of water. Generally, the weight of metabolically excreted matter is equal to the weight of the absorbed matter.

The existence of life is manifested in the continual activity of an organism; as soon as activity stops, life is considered ended. The activities of an organism are varied, yet no matter what the activity all require energy consumption including the supply of potential energy and the production of kinetic energy. Potential energy comes from the nutrients in foods and the oxidation of nutrients produces kinetic energy. These energies provide the necessities for human body activity.

The energy produced and consumed by the human body each day is measured in kilocalories and is called the metabolic rate. The minimum standard of the metabolic rate is called the basic metabolic rate. The basic metabolic rate is the quantity of heat emitted by each unit of body surface area after lying down for 20-30 minutes with an empty stomach; this is indicated by kilocalories/meter<sup>2</sup>.hour. The average for a normal adult is 40 kilocalories/meter<sup>2</sup>. hour. The total basic metabolic heat output of a medium built adult male is about 1440 kilocalories/day. Actually, each day people have varying degrees of physical activity. The energy consumption of physical activity is great and increases in accordance with the increase of the strength of the activity. The increase of heavy labor is several hundred calories per hour. The increase of energy consumption for mental labor and light muscle work is relatively small and the maximum increase is only several tens of kilocalories per hour.

The source of human body energy is the oxidation of food after it is digested and absorbed. People also require a certain amount of moisture to maintain their body liquids flow, matter exchange and balance of liquid inside and outside of the tissues. Therefore, food, oxygen and moisture are necessary provisions for life.

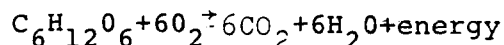
Sometimes human body activities cannot avoid encountering some type of harm such as skin peeling, hemorrhaging, sprained joints and tendon injuries. Furthermore, tissues are always in a degeneration and regeneration process, especially the mucous membrane and epidermis. There are also some cells which continually grow and continually fall out such as hair and nails. Thus, continual regeneration, total duplication and replenishing are necessary. Recovery and repair require matter and the origin of the matter is mainly food protein. Each day a person requires 20-30 calories of protein for this type of supply.

The human body also requires various inorganic salts and vitamins. Their metabolism does not produce energy but only maintains various body activities and the needs for normal metabolism. Fortunately, natural foods and moisture separately contain an abundance of vitamins and minerals so that it is only necessary to have proper distribution and then there will not be anxiety about a lack of this type of supplementary vitamin.

Food heat energy production arises from the oxidation of fats, carbohydrates and protein. On the average, complete oxidation of 1 calorie of a carbohydrate can produce 4 kilocalories of heat, 1 calorie of fat produces 9 kilocalories and 1 calorie

of protein produces 4 kilocalories.

Carbohydrates that exist in food are starch, various carbohydrates and sugar. After digestion, they all become monosaccharides - mainly glucose, fructose and galactose which are absorbed by the small intestines. After absorption it goes through a series of intermediary metabolism and finally is oxidized to become carbon dioxide and water. The oxidation of carbohydrates which produces heat can be simplified and written in the following formula:

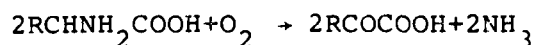


It can be seen from this formula that 1 molecule of glucose requires 6 molecules of oxygen for complete combustion and this produces 6 molecules of carbon dioxide and 6 molecules of water. The volume ratio of oxygen and carbon dioxide is equal to 1. The ratio of carbon dioxide and oxygen  $\left(\frac{\text{CO}_2}{\text{O}_2}\right)$  is called the respiratory quotient in physiology.

The oxygen in fat molecules is relatively small and therefore the produced carbon dioxide is less than its needed oxidation. Its respiratory quotient is equal to 0.71.

Protein digestion, absorption and intermediary metabolism are very complex. Its oxidation combustion is not thorough and so it does not completely become water and carbon dioxide. After it is digested in the gastrointestinal tract it becomes amino acid and is absorbed by the small intestines. After the amino acid goes through a series of chemical decomposition and synthesis, besides producing carbon dioxide and water, it also produces urea, ammonia, creatinine etc. which are excreted in the

urine. We will leave aside for the moment the series of intermediary metabolism changes. The oxidation of protein can be written in the following formula:



About 0.97 liters of oxygen are needed for the oxidation of each gram of protein in the body. This produces about 0.77 liters of carbon dioxide and the respiratory quotient is 0.8. See table 6-1 for the oxygen needed to oxidize food in the body and produce carbon dioxide and energy.

	1 需要氧气(升)	2 产生二氧化碳(升)	3 呼吸商	4 放出的热能(千卡)
5 每克糖	0.83	0.83	1.0	4
6 每克脂肪	2.02	1.43	0.7	9
7 每克蛋白质	0.97	0.77	0.8	4

Table 6-1 The Oxygen Needed to Oxidize Food in the Body and Produce Carbon Dioxide and Heat Energy

1. Needed oxygen (liters)
2. Carbon dioxide produced (liters)
3. Respiratory quotient
4. Emitted heat energy (kilocalories)
5. Each gram of carbohydrate
6. Each gram of fat
7. Each gram of protein

The production of nutrition, digestion, absorption, synthesis and energy do not embody all of the various aspects of the human body metabolism. Another aspect of human body metabolism is waste and the metabolized products that are eliminated. The oxidation of nutrient matter produces carbon dioxide and water. The former is eliminated by the lungs and the latter is

eliminated in urine, sweat, feces and exhalation. In a small airtight environment, if the eliminated carbon dioxide and water are not processed properly within a short period of time it can accumulate to a level causing harm to the health. Aside from carbon dioxide and water, the metabolism of protein also produces urea, uric acid, ammonia, creatinine etc. Most of it is excreted by the kidneys. Minerals and vitamins are also excreted in feces and urine. Furthermore, all foods are not digested and absorbed. Among these, cellulose and tendon cannot be digested and absorbed. Furthermore, after a great deal of digestive juice enzymes, protein in food and other nutrient semi-digestive matter which cannot be digested and absorbed reach the large intestines, because of bacterial decay and fermenting there is produced a large quantity of harmful matter. The large quantity of various microorganisms existing in the large intestines make use of the remaining food nutrients and propagate ; among these the protein semi-digested matter undergoes bacterial decay and then produces various harmful matter and gases. However, they also produce nutrients that are beneficial to the human body and which can be used for human body absorption. The hydrogen, hydrogen sulphide, methane, carbon dioxide, skatole, phenol and skatolin in urine, feces and emission of gas from the bowels are all harmful. The microorganisms in feces can also become the origin of infectious diseases. If the concentrations of some volatilized materials such as hydrogen sulphide, phenol, methane and skatole are very low they can cause people to feel ill or

bring about mucous membrane irritation. In short, these wastes, whether they are gases, liquids or semi-solids, must be properly dealt with and only then can an airship cabin's health environment be maintained.

## Section Two    Food Supply

### 1. Food Required for Space Navigation

Which food ingredients does an astronaut require each day? This is a question that must first be resolved in order to guarantee life in space navigation.

A healthy 35 year old astronaut is taken as an example. Given that the body surface area is 2 square meters, each day's basic metabolism produces an average of 1,750 kilocalories of heat energy. The metabolism rate of work done while sitting is 20% higher than the basic metabolism rate. When performing light work, the metabolism rate increases 1.8-2.6 kilocalories/minute. When wearing a pressurized spacesuit, the metabolism rate climbs 7 kilocalories/minute. Calculating from these facts, the total metabolism rate of each astronaut per day is about 2,500 kilocalories; this includes a 500 kilocalorie metabolic heat production during 7-8 hours of sleep, 1,080 kilocalories during 12 hours of sitting and doing very light work, 216 kilocalories during 2 hours of instrument control, 310 kilocalories during 2 hours of complex work and 420 kilocalories during 1 hour of physical exercise and medium work. If we add on a reserve of 300 kilocalories then the required heat by each astronaut per day can be calculated at 2,800 kilocalories.



Based on the above mentioned metabolic standard and combined with the nutritional needs of the human body, the food standard for each astronaut per day can generally be planned as follows: 100 grams of protein, 118 grams of fat and 308 grams of carbohydrates. The total heat of these foods is 2,770 kilocalories. Besides this, the following vitamins should also be supplemented: 200 milligrams of C, 100 milligrams of P, 10 milligrams of B<sub>1</sub>, 4 milligrams of B<sub>2</sub>, 100 milligrams of E, 20 milligrams of nicotinic acid and 30 milligrams of PP.

The food standard for people with smaller statures can be less than the above mentioned quantities. For example, the average body surface area of a Chinese adult male athlete is approximately 1.7-1.8 meters<sup>2</sup>. The amount of food required each day is fixed at 2,410 kilocalories. His required amount of food distribution and oxygen is shown in table 6-2.

1 食 物	2 热量(千卡)	3 重量(克)	4 氧 需 量		7 二氧化碳排出量(克)
			5 (升)	6 (克)	
8 碳水化合物(糖)	1200	300	297	415	585
9 蛋 白 质	400	100	100	140	162
10 脂 肪	810	90	179	250	230
11 总 计	2410	490	576	805	977

The Average Amount of Food and Oxygen Required by a Chinese Male Athlete Per Day

Key, next page

1. Food
2. Energy (kilocalories)
3. Weight (grams)
4. Oxygen required
5. (liters)
6. (grams)
7. Carbon dioxide eliminated (grams)
8. Carbohydrate
9. Protein
10. Fat
11. Total

In reality, the intake of food during space navigation often does not reach the above mentioned standards. The average intake of food for each person per day fluctuates within the range of 1,725-2,527 kilocalories. Why is this estimated standard not attained? One reason is that under weightlessness the physical strength load is lighter and so consumption is less than on earth; secondly, the amount of physical activity during space navigation is relatively small; thirdly, some astronauts incur space sickness or become nervous which causes a loss of appetite.

Besides the metabolic requirements, an astronaut's food supply should also be light in weight, small in size, tasty, able to be stored for a long time, easy to absorb, have little residue and be suitable for being packaged in a weightless environment. It is best if the food is edible without having to be heated, that the moisturizing process of dehydrated food be quick and that it be easy to carry. Based on the design requirements of the American Apollo spaceship, the packaged weight of food was 0.0833 kilogram package/kilogram of food and the storer weight was 0.072 kilogram storer/kilogram of food. The total package and storer weight was 0.1553 kilograms/kilogram of food (see table 6-3).

1 耗量(公斤/人·天)	2 食物消耗 (公斤/人·天)	3 3人30天的食品(包括贮存器和 包装在内)的总重量(公斤)
0.83	0.47	49
0.91	0.51	53
1.13	0.63	65
1.35	0.76	78
1.58	0.89	92

Table 6-3 One Example of a Design for an Astronaut's Food and Package Weight

1. Oxygen consumed (kilograms/person · day)
2. Food consumed (kilograms/person · day)
3. The total weight (kilograms) of food for 3 people in 30 days (including the storer and package)

Note: If the heat of the frozen dehydrated food is 6.0 kilocalories/gram, the relation of the body area and weight is 500 kilograms/meter<sup>3</sup>. The plan requires that the package weight be 0.0833 kilogram package/kilogram of food and the storer weight be 0.072 kilogram storer/kilogram of food. The total weight of the package and storer is 0.15 kilograms/ kilogram of food.

Based on the actual experiences of astronauts, an astronaut's food should be suitably increased with calcium, potassium, phosphorous and vitamin D or these ingredients can be supplemented by the oral digestion of a pill or tablet. The aim is to guard against the loss of calcium and osteoporosis under weightlessness. Table 6-4 is a proposal for minerals in an astronaut's food ration.

1 成分	9 一昼夜食物的平均含量	17 成分	25 一昼夜食物的平均含量
2 绝对干物质	10 517.50(克)	18 氯	26 4.29(克)
3 硫	11 3.40(克)	19 铁	27 79.97(毫克)
4 磷	12 1.12(克)	20 铜	28 5.92(毫克)
5 钙	13 0.90(克)	21 锌	29 25.23(毫克)
6 镁	14 0.27(克)	22 钴	30 10.23(毫克)
7 钠	15 5.91(克)	23 硼	31 2.0(毫克)
8 钾	16 1.89(克)	24 硅	32 103.47(毫克)

Table 6-4 A Proposal for Mineral Ingredients in Each Astronaut's Food Ration Per Day

1. Ingredient
2. Absolutely dry material
3. Sulphur
4. Phosphorous
5. Calcium
6. Magnesium
7. Sodium
8. Potassium
9. The average content of food in one day and night
10. 517.50 (grams)
11. 3.40 (grams)
12. 1.12 (grams)
13. 0.90 (grams)
14. 0.27 (grams)
15. 5.91 (grams)
16. 1.89 (grams)
17. Ingredient
18. Chlorine
19. Iron
20. Copper
21. Zinc
22. Cobalt
23. Boron
24. Silicon
25. The average content of food in one day and night
26. 4.29 (grams)
27. 79.97 (milligrams)
28. 5.92 (milligrams)
29. 25.23 (milligrams)
30. 10.23 (milligrams)
31. 2.0 (milligrams)
32. 103.47 (milligrams)

The use of food during space navigation should adapt to the conditions of weightlessness. Based on the actual experiences of astronauts, plastic tubes can be inserted into the mouth for water and liquid substances; the other food can be eaten one piece at a time in small strips or chunks. All of the food can be put in plastic containers or soft tube packages. A special heater can be used for heating. In considering the possible high oxygen density in the airship cabin, the use of direct fire for heating should be used so as to avoid the danger of catching fire.

## 2. Dehydrated Foods

In order for the food to be conveniently stored for a long time and be light of weight, space navigation requires the use of dehydrated foods. Formerly, the method for food dehydration was high temperature dry roasting. This type of prepared food was not only inferior in taste to fresh food but its nutritional value was also noticeably lower. For example, in heated dry food the protein deteriorates. The chemical activity of the protein molecules rises causing the fermentation speed of the proteins and carbohydrates in the stomach to be dissimilar. Therefore, the body's use of protein is incomplete. Long term use of high temperature dried food can also produce a loss of vitamin C. In other words, roast dried food is not ideal as food for astronauts especially for long term use.

In recent years, relatively advanced techniques have been utilized such as food vacuum freezing dehydration to make so-called sublimated dehydrated food. The preparation method is to

first quickly freeze the food under a low temperature of -30 to -40°C and later to slowly heat it in a vacuum disiccator so that the water in the food is directly sublimated from a frozen state to be dehydrated. The advantages of this type of dehydrated food are that the taste is close to that of fresh food and remoistening is convenient and can be done at room temperature or under 30-45 °C. Experimental research has shown that in recent years there were no major negative effects of long time use of sublimated dehydrated food.

Naturally, there is no denying that there is an adaptation period for getting accustomed to eating sublimated food. Moreover, some people can have reactions when eating this food for a long time such as increases in gastric hydrochloric acid, blood free hydrochloric acid, plasma protein and bile and a decline in blood serum free amino acids. After the experiments, the phagocitic activity in the white blood cells became active. Some people also had a negative balance of calcium. The vast majority of writers unanimously agree that even though there are the above mentioned and other reactions, it is feasible to take this type of food for several months. In order to prevent loss of calcium, each day 0.8-1.1 grams of calcium can be supplemented or the amount of calcium in the food can be raised 1.2-1.5 grams. The taste of sublimated food is close to that of fresh food, yet it is still a little lacking. When eating in a low air pressure environment, the differences in subjective perceptions are even greater than under normal air pressure..

Another method for preparing for suitable for long term storage has been developed in recent years. The method is that the food sustains a certain dosage of ion radiation. This type of radiated food is similar to fresh food in color, smell and taste and can be kept for several months without spoiling. It appears that this type is possibly a food preserving method that has a future in space navigation.

In order to prevent food from spoiling, some chemical agents formerly used in households can be used. For example, acid preservatives, borides, sulphur salicylate and citric acid; salt preservatives such as sodium chloride, sodium citric acid; and a broad spectrum of antibiotics such as penicillin and aureomycin.

### 3. Chlorella Foods

It is difficult to depend on eating stored food in long term space navigation. On the one hand, it is difficult for food to be preserved for a long time without deteriorating. On the other hand, the longer the navigation time the more the stored food area and weight must increase. This can possibly become a tremendous and excessive burden for the airship and thus adds to the difficulty of long term space navigation. In order to overcome this difficulty, many biological workers and engineers have spent a great deal of energy to foster growth to provide lower animals for food and set up an ecosystem in an airtight environment. After years of research by a great number of people, it was discovered that any type of chlorella was relatively ideal. However, there were many

problems which were not easy to resolve. Therefore, it is possible in the foreseeable future to set up a closed ecosystem in space navigation but this is still envisioned and cannot be realized.

For this reason, we do not write in detail on this subject. Instead we only present a general introduction about it.

Chlorella is a type of food with an abundance of nutritional value; the protein component is over 50% and it has a great deal of fat and carbohydrate. It grows quickly so that in 24 hours it can grow 7-8 times its original amount. Yet there are still many problems that exist for it to be used as a type of food. Here we will argue several points from the negative side to make it even more understandable.

First, chlorella has a special stench which is why people detest it. In order to eliminate this stench, the methods of volatilization and dehydration must be used.

Second, in order to improve its taste some people propose to mix it in with common foods. For example, to mix it in flour to make cakes or cookies, mix it with sugar to make candy or chocolate sweets. If done in this way, when chlorella is used as a food for a long time it can also affect human health. For example, if a dry weight of 10-15 grams of chlorella is eaten each day, after a long time no noticeable effects are seen in the human body. Yet, if even more is eaten each day, after a long period of time there can be poor digestion manifested in belching, nausea, lack of protein absorption, accumulation of intestinal gas, abdominal distention, a change in the number of bacteria in the intestines, an increase in defecation, drying up of urine and a loss of



appetite. When a dry weight of chlorella over 100 grams is eaten each day some people even have symptoms of poisoning such as limb extremity itching, cyanosis, chills darkening of colors as well as swelling of the toes and eyelids. It can be seen from this that chlorella cannot be used as a main food for a long time. For this reason, most of the research on chlorella has been halted.

### Section Three    Gaseous Metabolism

#### 1. The Gaseous Metabolic Rate of the Human Body

The gaseous metabolic rate is the most important cycle in life activity as people continually inhale oxygen and eliminate carbon dioxide and other gases. The human gaseous metabolic rate is closely related to work, temperature and food. The data in table 6-5 shows that the difference in oxygen consumption between rest and heavy work can be as high as 10 times.

An astronaut's required oxygen can be fixed at 576-650 liters or 805-930 grams per day but this also depends on the amount of work performed per day. Table 6-5 and chart 6-1 both present data on this.

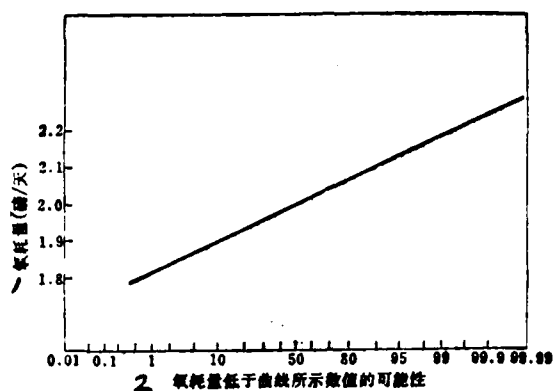


Chart 6-1 Designed Requirements of Oxygen Consumed by Each Person Per Day

1. Oxygen consumed (pounds/day)
2. The numbers shown below the line are the possible oxygen consumption

1 工作量和性质	7 正常空气呼吸量(升/分)	13 氧耗量(升/分)
2 休息	8 6~15(21%氧)	0.2~0.4
3 轻工作	9 20~25(21%氧)	0.6~1.0
4 中度劳动	10 30~40(21%氧)	1.2~1.6
5 较重劳动	11 40~60(21%氧)	1.8~2.4
6 重劳动	12 40~80(21%氧)	2.5~3.0

Table 6-5 The Average Amount of Oxygen Consumed for Different Amounts of Work

1. Amount and type of work
2. Rest
3. Light work
4. Middle degree work
5. Relatively heavy work

6. Heavy work
7. Normal air respiration (liters/minute)
8. 6-15 (21% oxygen)
9. 20-25 (21% oxygen)
10. 30-40 (21% oxygen)
11. 40-60 (21% oxygen)
12. 40-80 (21% oxygen)
13. Oxygen consumed (liters/minute)

## 2. Methods of Oxygen Supply

Based on existing technical data and practice reports, oxygen can be supplied from two major sources: one is stored oxygen and the other is regenerated oxygen. There are three types of stored oxygen: compressed oxygen, liquid oxygen and chemically released oxygen. There are many types of regenerated oxygen and these can be divided into two major categories: the first is the physical chemistry regeneration method and the other is the biological regeneration method. Stored oxygen is more reliable and in the past was used in space navigation. It is suitable for short term navigation of several days to several weeks. Here we will separately write on the advantages and disadvantages of various oxygen supply methods.

### 1. Stored Method

#### (1) Raising the Oxygen Pressure in the Cabin

This can be an easy oxygen storing method for short navigation of less than 12 hours.

#### (2) Compressed Oxygen

Compress the stored oxygen and place it in a pressure enduring container. Compression can reach 500 atmospheric pressure yet 1 kilogram can generally only store 361 grams of oxygen.

Because it is required to withstand this type of high pressure the walls of the container must be very strong and tough and therefore the ratio of the weight of the container and the weight of the oxygen is usually 7-10:1. When a plastic container is used for the compressed oxygen, the ratio of the container and oxygen weight can drop to 3.3:1. If an old style oxygen tank is used and the oxygen consumed by each person per day is calculated to be 800 grams it needs a 6-8 kilogram container. When the problems in short term navigation are not great and the navigation time becomes longer and longer, if it is calculated by the month or year the use of this type of stored oxygen can involve the airship's load ability; if 8 kilograms are needed each day, 240 kilograms are needed in 1 month and 2,880 kilograms are needed in 1 year. This weight is actually quite sizeable.

### (3) Liquid Oxygen

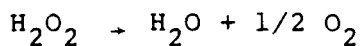
Liquid oxygen is very economical as regards container weight; each kilogram of oxygen only requires 2 kilograms of a container yet it has other shortcomings. First, it easily evaporates and leaks out so that it must be stored in a low temperature tank and another device must be added to the airship; second, under weightlessness the liquid oxygen jumps to the valve so that the valve cannot open and close and it easily freezes and blocks the valve; third, vaporization speed requires a set of devices to regulate it. If these problems are solved, when used for long term navigation the problems of weight and leaking gas are still not thoroughly resolved.

When used for shorter navigation it is relatively economical for raising the oxygen pressure in the airship but there is the danger of a fire breaking out. In order to decrease the danger of fire, at the same time as raising the oxygen pressure always lower the total air pressure in the cabin to the safety level. When navigation is longer than 1 day only relying on raising oxygen pressure in the cabin cannot satisfy the requirements. When navigation is less than 14 days the use of the stored liquid or gaseous oxygen method is relatively suitable.

## 2. Chemically Released Oxygen

There are mainly three types of chemical compounds:

(1) Hydrogen peroxide. This is a liquid which is easily stored, has very little automatic decomposition and requires a certain catalyst to be able to promote its fast decomposition. Decomposition speed is easily controlled. It has no toxicity, no irritation and does not cause fire. Under the promotion of a catalyst the decomposition reaction arises according to the following formula:



Only this reaction produces heat and causes the moisture to coagulate and form vapor. The vapor and oxygen must be separated in order to be able to be used. Under weightlessness it is relatively difficult to separate them.

(2) Other peroxides: the first type are alkali metal and alkaline-earth metal peroxides, superoxides and ozonide; for

example, potassium superoxide ( $\text{KO}_2$ ), sodium peroxide ( $\text{Na}_2\text{O}_2$ ), sodium superoxide ( $\text{NaO}_2$ ) and calcium superoxide ( $\text{CaO}_4$ ). After this type of chemical compound acts with water and carbon dioxide, oxygen is emitted. For example, after 1 gram of potassium peroxide absorbs water and carbon dioxide, 224 milliliters of oxygen are given off and at the same time it also acts to eliminate the foul smell in the air. 1,700 grams of potassium peroxide is a one day supply for one person. However, the respiration quotient for potassium peroxide is 0.67. This does not meet the physiological requirements of the human body (the body requirement is 0.82). Therefore, it is necessary to supplement carbon dioxide or burn up or absorb part of the oxygen so as to prevent the oxygen concentration from gradually rising and thus becoming a harmful high concentration. This type of peroxide has similar problems. Potassium peroxide also has shortcomings: first, the reaction is relatively slow and non-homologous making it unsuitable for use as emergency oxygen; second, when it decomposes to a certain level it loses effectiveness and thus the produced amount of oxygen is inferior to estimations; third, after the produced corrosive alkali ( $\text{KOH}$ ) becomes powder, if the filtering is not complete this will cause irritation of the respiratory tract.

(3) Another type of chemical compound that acts as chemically released oxygen are chlorates and perchlorates and chemical compounds of types (1) and (2) such as sodium chlorate ( $\text{NaClO}_3$ ). When sodium chlorate uses the chlorine and the original iron and barium oxide provides heat, oxygen is emitted. The product

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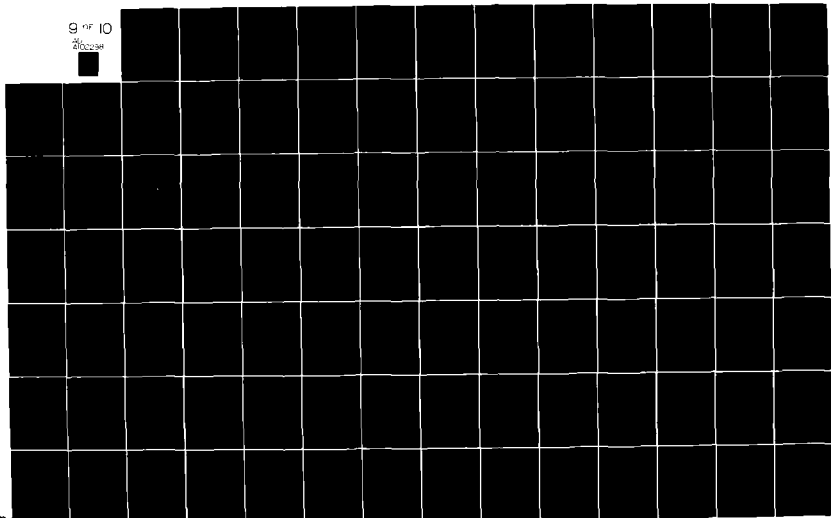
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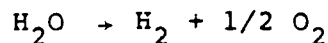
commonly used is candle shaped and its density of 2.4 holds 40% oxygen. One cigar-sized candle can supply a person for 15 minutes. The reaction is set off by matches or an electric spark and resembles lighting a candle. The two above mentioned chemical compounds can be used jointly and can be stored for an unlimited amount of time. 200 kilograms of chemical compound can supply a person for 1 month. They have the two important effects of eliminating carbon dioxide and supplying regenerated oxygen for respiration.

### 3. Regenerated Oxygen

#### (1) Physical Chemistry Method of Regenerating Oxygen

There are many kinds of physical chemistry methods for regenerating oxygen. Yet, all appear to use water and carbon dioxide to produce oxygen. The relatively successful ones are high temperature decomposition of carbon dioxide, ultraviolet ray decomposition of carbon dioxide, hydrogenation of carbon dioxide and electrolysis of lithium carbonate; among these the most useful in engineering which already have systematic design plans are water electrolysis and the Salmon(?) reaction of hydrogen and carbon dioxide.

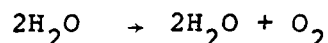
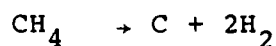
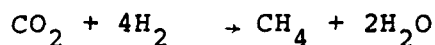
Water electrolysis produces hydrogen and oxygen according to the following formula:



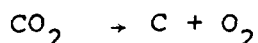
The Salmon(?) reaction occurs with carbon dioxide and hydrogen and produces methane and water. Afterwards, the methane



undergoes high temperature decomposition and the water undergoes electrolysis. The reactions are as follows:



The result of these three chemical reactions is:



Under a high temperature of 260°C, the Salmon(?) reaction can reach a 95% conversion efficiency; when a suitable catalyst is used the temperature drops and can reach a balanced conversion.

Methane high temperature decomposition provides some of the needed hydrogen for the Salmon(?) reaction and the remaining hydrogen comes from the water electrolysis. Very recently, published materials have shown that the already developed systems design for airships can cause the carbon dioxide pressure of the airship cabin to be maintained at a level of 3.8 millimeters on the mercury column for a long time without changing; each day 954 grams of carbon dioxide is absorbed and 828 grams of oxygen is produced. This is equal to 485 liters of carbon dioxide and 591 liters of oxygen. The respiration quotient is 0.81 which approaches human metabolism requirements.

It must be pointed out that this method requires the use of a molecular sieve and carbonization pool to concentrate the carbon

dioxide, high temperature and ionization equipment and a great deal of equipment is needed for preventing hydrogen gas and methane combustion explosions. Since power consumption is very great it is not suitable for navigations of 2-3 weeks. However, this method has a future for longer flights.

The use of ultraviolet rays (4,000 angstrom wavelength) to decompose carbon dioxide into carbon and oxygen is another method. Yet, in 90 minutes only 15% of the carbon dioxide is decomposed into oxygen and moreover it cannot mix with the vapour; if carbon dioxide is saturated by vapour and copper is used as a catalyst, carbon monoxide,  $\text{CH}_4$  and ozone will be produced. These are harmful to the human body and therefore this method still requires further research and improvement. At present, its application has still not been discussed.

## (2) Biological Photosynthesis of Regenerated Oxygen

The photosynthesis of plants is a well known fact in biology. Plants use light energy, synthesize carbohydrates from carbon dioxide and water and produce oxygen. This can be shown in the following formula; the chlorophyll in the photosynthesis gives rise to catalysis.



If we want to shift this action of the plant to a very small airtight cabin then it is necessary to select a type of plant which is small in size, that grows quickly, propagates

easily under artificial conditions and is able to absorb a large amount of carbon dioxide and produce a large amount of oxygen. Lower species of aquatic plants are more suitable. Using chlorella as an example, when it grows 1 gram dry weight of cells, 1 liter of oxygen can be obtained. Along with other similar types of plants (algae) it can use the carbon dioxide and nitrogen containing matter to produce oxygen. Its assimilation quotient ( $\text{CO}_2/\text{O}_2$ ) is close to the respiration quotient of the human body. However, there remain many problems in breeding chlorella so that it still cannot be used.

Below we will discuss the problem of the oxygen supply flow needed in an oxygen storage system. Under open ring respiration conditions, the exhaled gases are mixed with the surrounding gases and later inhaled again. The required respiration gas flow can be calculated according to the following formula:

$$\dot{W}_r = \dot{W}_c \left( \frac{P - P_c}{P_c M_c} \right) M_g$$

In the formula,  $\dot{W}_g$  is the respiration gas flow needed for open ring respiration;  $\dot{W}_c$  is the carbon dioxide elimination rate;  $P_c$  is the carbon dioxide partial pressure;  $P$  is the total air pressure;  $M_c$  is the carbon dioxide molecular weight;  $M_g$  is the total air pressure and composition of the respired gas. When the total air pressure is 1 atmospheric pressure of air, the required respiration air flow is 2.7 kilograms/person · hour. When the air pressure is 1 atmospheric pressure of pure oxygen, then the required respiration airflow is 0.7 kilograms/person · hour (the

carbon dioxide partial pressure is assumed to be 7.6 millimeters on the mercury column). When using a chemical reduction process to remove the carbon dioxide regenerated oxygen, the required respiration air flow can be lowered to 1.8 kilograms/person·day of air. The permissible cabin gas leakage rate is 0.9 kilograms/person·day.

During short navigation of less than 14 days the stored oxygen method can be used to supply oxygen. When navigation is longer than 14 days then the use of the gas regeneration system is more suitable.

Does living in a gas regeneration system create negative effects on the human body? Some people have lived for 90 days in a simulated airship cabin with a gas regeneration system which used a molecular sieve to collect the waste gas (carbon dioxide) and electrolysis to decompose (regenerate) oxygen. The four subjects lived well in the cabin and had no negative reactions. When the experiment was over their subjective sensations were good and there was no problem in regenerative living for 120 days.

### 3. The Elimination of Waste Gases

Humans not only inhale oxygen and eliminate carbon dioxide but also at the same time eliminate carbon monoxide. These useless and harmful gases must be eliminated at the proper time otherwise if a lot accumulates in the airtight cabin over a long period of time this can be harmful to the human body. For example, each day one adult will produce close to 1 kilogram of carbon dioxide

equivalent to about 500 liters. Even if the concentration of the original carbon dioxide in a narrow, airtight cabin is very low, less than 0.04% which is similar to that on the earth's surface, the astronaut continually exhales carbon dioxide. If it is not eliminated, in only a short time this can cause the concentration of carbon dioxide in the cabin to reach a level unendurable to the human body.

A chemical absorbent can be used to absorb the carbon dioxide and moisture exhaled by the human body and a filter can be used to filter the foreign matter and bad odor. There is very little carbon monoxide eliminated in the respired gases. Its effect on several days of navigation is not very great but it must be eliminated in long term navigation. There is volatilized matter in the waste gases and active carbon can be used to absorb it. Before active carbon powder or granules are placed in lithium hydroxide and absorbs the carbon dioxide, its power is very great. One container of active carbon can be used for several days up to more than 10 days. When waste material is covered with a layer of active carbon the stink can be eliminated. Yet, some relatively small molecular materials cannot be absorbed by active carbon and therefore other methods must be used. For example, silica gel or manganese, copper and silver or cobalt oxide compounds can satisfy these requirements. For example, it is unable to absorb carbon monoxide and another method must be used to handle it. One of the methods is to change it into carbon dioxide by means of an oxidizer and then use a lithium hydroxide to absorb it. Superoxidized

potassium has destructive organic poisonous gas and toxic mechanisms. Therefore, at the same time it absorbs carbon dioxide and moisture and releases oxygen it also absorbs many types of organic poisonous gases.

See table 6-6 for the chemical absorbents used for the carbon dioxide and moisture eliminated in respiration gases. Besides chemical absorption the filter process can also be used, for example the molecular sieve and compression method. The latter stores or eliminates out of the cabin the atmospheric compression with carbon dioxide and moisture and exchanges it for fresh air. The molecular sieve is a gas molecule absorbing material (for example, zeolite). It can absorb carbon dioxide and moisture waste gases and afterwards undergo a reverse process to release them. The released waste gases can be eliminated or decomposed by the regeneration and use of a reduction process. The reverse process of a molecular sieve (such as zeolite) can be completed by going through a vacuum process, dry heat process or electronic system; the weight of the latter is lightest.

1 吸 收 剂	6 二氧化碳清除剂(克)	7 被清除的二氧化碳和水(克)
Li	325	400
Li <sub>2</sub> O	700	810
MgO	920	1030
Mg(OH) <sub>2</sub>	1335	—
2 Na吸收后生成Na <sub>2</sub> CO <sub>3</sub>	1050	1250
3 Na吸收后生成NaHCO <sub>3</sub> + Na <sub>2</sub> CO <sub>3</sub>	750	900
4 CaO吸收后生成CaCO <sub>3</sub>	1290	1450
5 CaO吸收后生成80%Ca(HCO <sub>3</sub> ) <sub>2</sub>	775	970

Table 6-6 The Amount of Absorbent Required for Each Person's Carbon Dioxide and Moisture Per Day

1. Absorbent
2. Na<sub>2</sub>CO<sub>3</sub> produced after Na absorption
3. NaHCO<sub>3</sub> + Na<sub>2</sub>CO<sub>3</sub> produced after Na absorption
4. CaCO<sub>3</sub> produced after CaO absorption
5. 80% Ca (HCO<sub>3</sub>)<sub>2</sub> produced after CaO absorption
6. Carbon dioxide eliminating agent (grams)
7. Carbon dioxide and water eliminated (grams)

In order to guarantee that the unnecessary and poisonous ingredients in the absorbed gas are eliminated there must be a certain circulation of the cabin air especially under weightlessness when the air's free heat convection is lost and the circulation of gas must be carried out artificially. The speed of the gas circulation inside the cabin can be determined according to

the following formula.

$$V > \frac{a}{C - C_0}$$

In the formula:

V is the required gas circulation speed;

a is the removal speed of human body metabolic products with certain equipment;

C is the permissible limit of the concentration of these metabolic products in the cabin air;

$C_0$  is the concentration of these metabolic products in the circulated air.

#### Section Four    Water Supply

##### 1. Human Body Water Equilibrium

Human body moisture is in a moving equilibrium, the amounts taken in and eliminated are basically maintained equally; if a large quantity is taken in then a large quantity is eliminated and on the contrary if a little is taken in then a little is eliminated. Generally speaking, body moisture is maintained at a certain level and does not change within a given period of time; if the water level is too low this can cause symptoms of water loss so that tissue metabolism, blood circulation and kidney excretion are abnormal and this can also cause the accumulation of waste matter in the blood and cells. These types of phenomena are only seen in some patients who have cardiac illnesses, kidney diseases and patients who have an imbalance of electrolytes. Normal people



cannot incur this and it only occurs temporarily. Naturally, temporary dehydration can occur resembling the symptoms mentioned above. There are astronauts who lose body weight during short time navigation because of water loss yet after returning to earth and given a supplement of water they can recover their body weight within a short period of time.

See table 6-7 for the intake and output of water in the human body. The numbers represent an adult male doing light work for 8-10 hours. Chart 6-2 shows the effects of gas heat on the amounts of water, food and oxygen required. In the table, the mention of skin evaporation indicates the direct volatilization by the skin and externally contacted mucous membranes such as the oral-nasal cavity and eye mucous membranes. However, it does not indicate the sweat gland perspiration moisture (this is called unconscious sweating in physiology). Natural foods contain a large amount of moisture but frozen dried processed foods must have water added in order to be swallowed. In the table the water in the food indicates the moisture absorbed by the food.

1 输出途径水(克)		7 摄入途径水(克)	
2	尿 1300	8	食物中的水 1500
3	粪 200	9	饮 水 1000
4	汗和皮肤蒸发 600		
5	呼吸 400		
6	总计 2500	10	总计 2500

Table 6-7 The Intake and Output of Water by an Adult Each Day  
Key, next page

1. Output channeled water (grams)
2. Urine
3. Feces
4. Sweat and skin evaporation
5. Respiration
6. Total
7. Intake channeled water (grams)
8. Water in food
9. Water consumed
10. Total

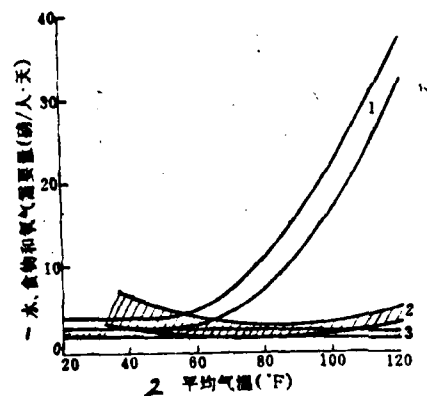


Chart 6-2 The Effects of Air Temperature on the Amounts of Water (1), Food (2) and Oxygen (3) Required Each Day by a Human

1. Required amount of water, food and oxygen (pounds/person . day).
2. Average air temperature (°F)

## 2. Methods for Supplying Water

Methods for the supply of water is a problem in space navigation. The storage method can be used for short term navigation. Water spoils when stored for a long time and only if water

permeated with organic matter and containing little salt is in a sealed glass or plastic container can it be preserved for 6 months. If a silver seal is used then the permissible amount of the above mentioned impurities must be less than 0.1-0.4 milligrams/liter and if a silver nitrate seal is used then the permissible amount of the above mentioned impurities must be less than 1.5-2.0 milligrams/liter. When a pikromycin seal is used then the permissible amount of the above mentioned impurities must be less than 50-100 milligrams/liter. When it is necessary to preserve water for a long time, the use of chlorine as a disinfecting and purifying agent is not ideal because when stored for a very long time the concentration of the needed chlorine is too great and is harmful to the human body. The use of ionized silver is more suitable. Aside from this, silver salt, copper salt, manganese salt and hydrogen peroxide solution can also be used. Hydrogen peroxide solution can also serve the dual purpose of storing oxygen and storing water.

In order to navigate for a relatively long period of time a regeneration method can be used for the water supply which is using the moisture eliminated by humans again after it is reduced. Based on the results of experiments, the regenerated water from urine is not sufficient by itself to completely supply drinking water for humans. Each person requires about 0.21 kilograms (not including water for sanitary use) per day. If common food is used instead of dehydrated food then 2.1 kilograms of water can be obtained from the common food. If water in the feces is

reduced and used by people then the use of dried fruit (non-dehydrated food) can be made to satisfy human water needs. When considering human work, physical exercise and possible temperature rises in the cabin as well as the use of dehydrated food, then besides the regenerated water from urine and feces, it is also necessary to supplement the supply of water. The supplemental supply of water can be provided from the accumulated moisture in the air exhaled by the human body and afterwards it is condensed into water. However, this type of water often contains impurities including a good deal of ethyl alcohol. After the use of active carbon and chemical agent purifiers, this type of water is not harmful to people and can be taken for a long time. From the moisture collected in the exhaled gas, the chemical agent absorption and molecular sieve methods (see earlier discussion) can also be used.

There are many methods for the regenerated clean water from urine and feces: (1) the vacuum distillation method; (2) the heating distillation method; (3) the catalysis method; (4) the osmosis filter method; (5) the ion exchange method. In order to avoid high temperatures and energy waste the outer space vacuum conditions are used to carry out vacuum distillation during navigation and regenerate water from urine and feces. This is a relatively good method. Yet, because of this, the regenerated water can only be consumed after one more time of active carbon and chemical agent purification.

## Section Five    The Closed Ecology System

### 1. The Chlorella System

During navigation of more than one year, the use of the storage method to guarantee human body life supplies is difficult. Some people calculate the 2 month journey (according to theoretical calculations it will take much longer) to and from Venus, the weight of the supplies needed for one person is over 700 kilograms and adding on the weight of the packaging and storers it approaches 1 ton. If a more than 2 year journey is taken to and from Jupiter then the total weight of the needed supplies, its packages and storers is about 20 tons. This is indeed a tremendous burden for an airship. Moreover, whether the food and water can be stored for 2-3 years and not deteriorate is another matter. Therefore, longer navigations require improved means of supply.

The first improved method to be mentioned is the so-called half cycle method which uses the regeneration process to supply the oxygen and water and uses nutrients and vitamin pills to substitute for and supplement part of the food. This method has already been partially realized in the most recent space navigation. Nevertheless, each person required about 2 kilograms per day. Adding on the weight of the equipment during 30 days of navigation one person required 90 kilograms. Generally, this type of supply method had no problems for several months of space navigation; only for even longer navigation is it necessary to find an even better method.

In order to satisfy the requirements for relatively long time space navigation and not have the airship burden be too heavy, many people have proposed the use of a closed ecology system which is the formation of a "small world " inside the airship. In this "small world" various material cycles can attain self stabilization.

The existence of life on earth depends on the environment and living things. The mutual relationship between living things is the continual cycle of a mutually dependent ecology system. If an airship's airtight cabin can artificially create a very reduced closed ecology system then this is the most ideal. Although, at present, we are far from realizing this ideal, yet it signifies mankind's grand intention to conquer nature. Therefore, a brief introduction must be written with the hope that some day this intention can be realized.

The key link embodying the closed ecology system depends on man's excrement and water to grow green plants. The advantages of this type of plant are not only that it can absorb carbon dioxide and give off oxygen but it can also absorb the excretions of humans. Moreover, the plants can possibly supply people with food. The most hopeful among this type of food is chlorella. The photosynthesis of this type of plant has a high efficiency, it grows quickly (in one day and night its weight can increase about 7 fold) and its nutritional value is high. The assimilation quotient of chlorella (carbon dioxide/oxygen) is basically the same as the respiration quotient of humans. If only the carbon dioxide and oxygen cycle are considered then

2.3 kilograms of chlorella can provide the needs of one person. Yet, the culture system of chlorella includes containers, a lighting system and water all of which is relatively heavy; theoretically the chlorella system weight required for the carbon dioxide and oxygen cycle for one person is only about 70 kilograms. Yet, the weight able to be accomplished in present technology requires about 500 kilograms. If this is applied to human consumption then a dry weight of 1.1 kilograms is needed by each person per day, the wet weight is calculated as 4.3 kilograms and the nurturing and processing systems must exceed 800 kilograms. If this is the case, the closed ecology system is unsuitable for navigation of less than half a year let alone the many unresolvable problems that still exist in using chlorella as a major food. We will not repeat what has already been discussed previously.

Furthermore, many problems still exist in the chlorella closed ecology system itself. For example, the chlorella's ageing, genetic variations and toxicity produced from bacterial infection. Aside from this, the various special conditions in space navigation such as radiation, overweightness and vibration can all affect its growth. Moreover, the gas exchange between chlorella and the human body is not absolutely balanced, it produces a small amount of carbon monoxide which after a long time can obstruct health. In brief, although the chlorella closed ecology system is theoretically very ideal yet its practical application is still very far off.

## 2. Other Closed Ecology Systems

Because of the existence of a series of problems in the chlorella closed ecology system some people have considered and tested other systems. Some people have tested bacteria. It is said that certain types of bacteria with weights of 700-800 grams contain 90-100 grams of oxygen and 50-60 grams of nucleic acid. The human body can digest 93% of the nitrogen of this type of bacteria, only its fat is difficult for humans to absorb. Yeast has also been considered but each day's food consumption cannot exceed 5-7 grams and if more is consumed one is easily poisoned. A large number of lower species organisms have been tested but none were ideal..

Aside from this, other plants have also been tested, especially aquatic plants. Furthermore, small animals that can feed off of aquatic plants as well as raising fish, chicken and ducks have been examined. Yet, at present, there is still not a conclusively established closed ecology system suitable for space navigation.

## Section Six Environmental Sanitation in the Cabin

### 1. Environmental Conditions in the Airship Cabin

In order to guarantee the life safety and work capabilities of an astronaut, there should be certain requirements for the environment inside the airship cabin. This problem involves the airship's structure and weight as well as its technical level of complexity. Thus, it cannot be considered solely from



the angle of medical science. Therefore, it is very necessary to select the gas conditions inside the airship cabin. The cabin gas environment can be divided into the following two categories.

1) To basically maintain the air pressure and gas components in the cabin the same as on the earth's surface. The advantages of this method are that it allows people to be comfortable and there is no danger of fire. The shortcomings are that the air pressure inside the cabin is high, airship weight is great, there is a small percentage of leaked gas and there is a great danger of depressurization sickness.

2) Use of low air pressure and highly concentrated oxygen inside the cabin. Its advantages are that it can lighten the weight of the airship to a suitable level, a very small percentage of the cabin leaks gas and the danger of decompression sickness is relatively small. Its shortcomings are that fire easily breaks out and before takeoff an astronaut must carry out oxygen-breathing and denitrification. When taking off, 60% oxygen and 40% nitrogen can be used inside the cabin. After takeoff, the first day's oxygen concentration rises to 80% and on the second day it rises to 90%.

## 2. Sanitary Measures and Handling of Wastes

An airship is an airtight cabin and bad smells cannot flow outside. If they are not eliminated then they will accumulate. Cabin size is limited and therefore the various bad smells and toxic gas pollution must be prevented. Dust inside the cabin

is also a problem. Under weightlessness, dust flies everywhere and cannot automatically fall on the floor. Therefore, attention must be given to eliminating dust and preventing pollutants from flying around in the airship cabin. In order to guarantee the cleanliness of gases inside the airship cabin, the gases inside the cabin must be taken out and replaced. The frequent removal of smells and gas purification measures are also necessary.

Regarding the problem of bacterial pollution, tests carried out on living in an airtight cabin have discovered that in a simulated 14 day lunar voyage bacterial pollution was not severe. Only the urine and feces storers had a relatively large amount of bacteria. Because of this, the sanitation of the excrement storer must be given special attention so as to guarantee that these bacteria are not diffused to the outside. An astronaut's individual hygiene is very important for preventing bacterial pollution.

The most important problem in cabin sanitation is the handling of excrement. During short term navigation, excrement can be stored in a container and this container should be sealed. In order to prevent bacterial pollution, there should be a germicide inside the cabin. For example, tetrachloride, calcium chloride and chlorophenylamine keep when the temperature is below  $-7^{\circ}\text{C}$ . Tetrachloride can also be used to eliminate matter in the poison container and tablecloth. Throw measures must be used during long term navigation to eliminate excrement from the

cabin. The total volume of human excrement is about 0.004 meters<sup>3</sup> per day. Therefore, keeping excrement in the cabin when navigating longer than 1 month is not convenient. A relatively good method for handling urine and waste water during long term navigation is to regenerate the usable pure water after recovery. This can resolve the problem of the airship's supply of water and to a large extent resolves the problem of handling excrement.

Another problem in cabin sanitation is the elimination of human body metabolic heat. If metabolic heat is not eliminated then the air temperature inside the cabin can gradually rise up to a level of human non-endurance. A heat radiator can be used for metabolic heat elimination.

#### Section Seven    The Overall Plan of the Life Support System

We have already basically discussed the supply of needed materials for supporting human life and handling excrement. Here we will discuss the overall plan of an airship's life support system.

Up until the present there is still no practical method that can produce food in an airship (space station), lunar station or other celestial body. That is to say to live in an atmosphere far from earth it is necessary to carry food from earth. Only the air and water can be replaced but the weight of the needed equipment is still very heavy. Chart 6-3 shows a comprehensive replacement method of air and water under airtight conditions. Because 2 tons of equipment are needed it still cannot

be used for short term space navigation but it is very necessary for long term navigation. It was developed for the oxygen and water required by 4 astronauts living for 1 year under weightlessness. The exhaled carbon dioxide, moisture and air pollutants, the water used for washing and urine can be used again as pure oxygen and pure water after filtering, absorption, heating, freezing, catalysis and electrolysis. The evaporation method is used to recover water. The surplus vapour in the cabin air and used water and urine collected in the water trough are sucked up to another end by the action of the wick capillary, the hot air flow causes it to evaporate into vapour and after cooling and filtering it becomes pure water and flows into the storer. The pollutants and dregs then remain on a replaceable wick.

Air recovery is relatively complex and requires a series of physical and chemical purifying and replacing processes. Generally speaking, it is first necessary to extract the surplus water and carbon dioxide from the exhaled gas and eliminate the pollutants in them. This developed equipment uses a demister, carbon dioxide collector and an active carbon filter with a catalytic combustor to separate completely the above mentioned tasks. Afterwards there is electrolysis of the water and reduction of the carbon dioxide to produce oxygen. This equipment has a water electrolysis unit and carbon dioxide reduction unit; their structures are relatively complex and the products are oxygen and carbon. The air supply is reused but the carbon is temporarily discarded.

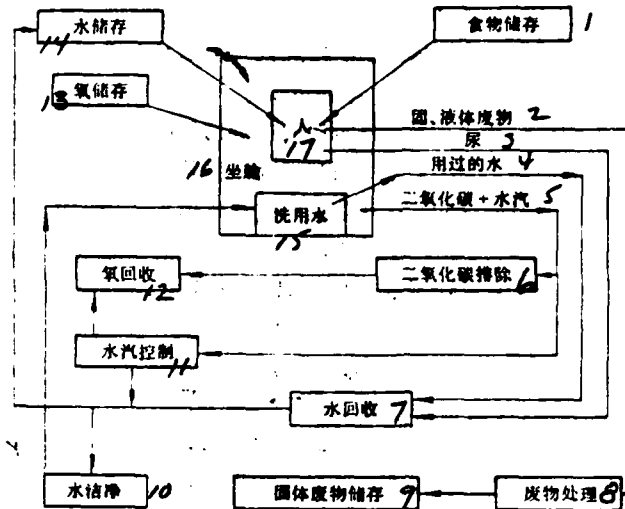


Chart 6-3 The Overall Plan for A Manned Cabin Life Support System

1. Food store
2. Solid and liquid wastes
3. Urine
4. Used water
5. Carbon dioxide + moisture
6. Carbon dioxide elimination
7. Water recovery
8. Handling of wastes
9. Solid waste store
10. Clean water
11. Moisture control
12. Oxygen recovery
13. Oxygen store
14. Water store
15. Water for washing
16. Cabin
17. Person

This equipment did not consider the food supply and the handling of solid wastes. If the relationships of the various

parts of the airship's life system are conceptualized, we can further draw a complete initial plan as shown in chart 6-3. This schematic chart does not reveal the specific design method and therefore table 6-8 is used to summarize the materials. In the table some things that have not been discussed in detail or problems that will not be discussed are also listed. Yet, in order to have a complete view they are all placed together for reference.

See next page for table 6-8

1 项目	2 物理的	40 化学的	56 其它	65 备注
2 氧气供应	13 1. 高压钢, 铜、玻璃 14 2. 低压钢, 铜、玻璃 15 3. 液态氧	41 1. 高氧化物, $KO_2$ , $NaO_2$ , $LiO$ 42 2. 过氧化氢, $H_2O_2$ , $NaO_2$ , $LiO_2$ 43 3. 其它, $NaClO_2$ , $KO_2$ 等	57 1. 水电解: $CO_2 + H_2 \leftrightarrow H_2O + C + 1/2 O$ $CO_2 + H_2 \leftrightarrow H_2O + CO$ , $CO_2 + 3H_2 \leftrightarrow 2H_2O + CH_4$ 58 2. 光分解, $CO_2 \leftrightarrow CO + 1/2 O_2$ , $CO_2 \leftrightarrow C + O_2$	69 短期航行, 采用高压氧和高氧化物结合, 水电解有前途, 为将来长期航行之用
3 二氧化碳控制	16 1. 冷冻成冰, 辐射板, 压缩机 17 2. 分子筛 18 3. 过滤膜 19 4. 活性炭	44 1. 氢氧化物, $NaOH$ , $KOH$ , $LiOH$ , $Ca(OH)_2$ 45 2. 高氧化物, $KO_2$ 46 3. 碳蜡	59 1. 氢化, $H_2CO_2 \leftrightarrow C + H_2O$ , $H_2CO_2 \leftrightarrow CO + H_2O$ , $H_2CO_2 \leftrightarrow CH_4 + H_2O$ 60 2. 生物, 藻类	70 $LiOH$ , $KO_2$ 已被应用, 其它尚需进一步研究
4 水的供应和控制	20 1. 冰冻 2. 蒸馏 3. 离心 21 4. 过滤 5. 分子筛 22 6. 冷凝	47 $LiCl$ , $KO_2$ , 硫酸, $Mg(ClO_4)_2$ (干), $CaSO_4$	61 生物纯化, 藻类	71 冷凝最简单, 特别是使空气水分凝结成为可饮的水
5 食物	23 1. 储存, 加工冷冻 24 2. 加工, 干燥, 罐头, 辐射, 真空冷冻, 包装	48 补充食物, 维生素, 矿物质	62 食物再生: 1. 藻类 2. 其它植物 3. 化学合成	72 食物再生还不现实, 必须从地面上去
6 座舱卫生和粪便处理	25 1. 储存 26 2. 甩掉 27 3. 热分解 28 4. 纯化 29 5. 蒸馏 30 6. 冰冻 31 7. 过滤	49 1. 化学分解, 氧化, 还原 50 2. 离子交换	63 生物分解, 氧化, 还原, 菌类, 细菌	73 垃圾储藏, 抽气机, 氧化降解等设备, 生物处理不现实
7 个人卫生	32 1. 洗身、洗衣等 33 2. 超声波处理	51 洗衣服、洗身用: 1. 水 + 肥皂 2. 酒精 3. 清洁剂	49 部分衣服可不要, 手巾用化学处理	74 航行二周以上要考虑洗澡问题, 干洗不满意
8 污染物	34 灰尘、头发、脱皮屑 其它	52 气味, 有害气体和物质, $NH_3$ , $CH_4$ , $CO$ , $H_2$ , $H_2S$ , 臭类, 酸, 醇, 吡啶等	65 细菌、芽胞、病毒, 由此产生酶有机物, $H_2S$ , $NH_4OH$ , $CO_2$ , $CH_4$ , 乳酸, 醋酸等	75 1. 过滤和吸收, 活性炭 76 2. 静电处理 77 3. 燃烧 78 4. 水, 氧化和吸收
9 温度控制	35 1. 主动控制, 压缩, 电热 36 2. 被动控制, 辐射板, 冷却剂			79 热源, 太阳、设备、人。除太阳对其它不能减少, 必须利用之。过剩的热由辐射和调气去其部分
10 所需电力	37 1. 太阳发电机 38 2. 太阳能电池	53 1. 化学电池 54 2. 燃料电池	66 核能发电(需要很好保护)	80 化学电池、燃料电池和太阳能电池已被应用
11 仪器和控制	39 传感压力, 温度, 湿度, 失火探测	55 氧, 二氧化碳, 氮控制, 温湿度显示和控制	67 传感器探测, 测量系统	81 仪表板, 显示, 通讯

table 6-8 is continued on next page

(续)

82 项 目	86 物 理 的	90 化 学 的	93 其 它	97 备 注
83 辐射屏蔽	87 座舱结构、材料	91 粮食、燃料、氧、水	94 设 备	98 尽可能加倍屏蔽
84 安全和生存设备	88 救生艇、救生舱、弹射设备、处理设备	92 救生艇	95 宇宙服	99 更好的预计和准备需要加强研究
85 姿态控制	89 自动稳定控制、惯性运动回旋器		96 手操纵控制、喷气反应器	

Table 6-8 Each Subordinate System of the Airship Cabin's Ecosystem (only offered as a reference; selection should be made according to specific circumstances)

1. Item
2. Oxygen
3. Carbon dioxide control
4. Water supply and control
5. Food
6. Cabin sanitation and the handling of excrement and urine
7. Individual hygiene
8. Pollutant
9. Temperature control
10. Auxiliary electric power
11. Instrument and control
12. Physical
13. High pressure tube: steel and glass fiber reinforced plastic
14. Low pressure tube: steel, glass fiber reinforced plastic and plastic
15. Liquid oxygen
16. Freezing makes ice; a radiation plate and a compressor
17. Molecular sieve
18. Filter coating
19. Active carbon
20. 1. Freezing 2. distillation 3. centrifugal
21. 4. Filter 5. molecular sieve
22. 6. Condensation
23. Storage: freezing process
24. Process: drying, canned, radiation, vacuum freezing, packaging
25. Stored
26. Disposed of
27. Heat decomposition
28. Purification



29. Distillation
30. Freezing
31. Filtering
32. Washing of body, clothes etc.
33. Supersonic wave processing
34. Dust, hair, peeling skin and others
35. Active control: compression and electric heat
36. Passive control: radiation plate and collant
37. Solar generator
38. Solar cell
39. Cabin pressure, temperature, leaked air and fire probe
40. Chemical
41. High oxides:  $KO_2$ ,  $NaO_2$  and  $LiO$
42. Hydrogen peroxides:  $H_2O_2$ ,  $NaO_2$  and  $LiO_2$
43. Others:  $NaClO_3$  and  $KO_2^3$
44. Hydroxides:  $NaOH$ ,  $KOH$ ,  $LiOH$  and  $Ca(OH)_2$
45. High oxides:  $KO_2$
46. Carbon barium
47.  $LiCl$ ,  $KO_2$ , silica gel,  $Mg(ClO_4)_2$ ,  $CaSO_4$
48. Supplementary food: vitamins, minerals<sup>4</sup>
49. Chemical decomposition: oxidation, urease
50. Ion exchange
51. Washing clothes and body:
  1. Water and soap
  2. Ethyl alcohol
  3. Cleaning agent
52. Smelly and harmful gases and matter:  $NH_3$ ,  $CH_4$ ,  $H_2$ ,  $H_2S$ , smell of feces, amine, phenol and indole
53. Chemical cells
54. Fuel cells
55. Oxygen, carbon dioxide, nitrogen control, temperature indication and control
56. Other
57. Water electrolysis
58. Light decomposition
59. Hydrogenation
60. Living thing: green alga
61. Biopurification: green alga
62. Food regeneration:
  1. Green alga
  2. Other plants
  3. Chemical synthesis
63. Biodecomposition: oxidation, protist, algae, bacteria
64. Part of clothing not needed: chemical processing of towels
65. Organic matter produced from bacteria, gemma and virus:  $HgS$ ,  $NH_4OH$ ,  $CO_2$ ,  $CH_4$ , lactic acid and acetic acid
66. Nuclear<sup>4</sup>electric power (requires very good protection)
67. Pollution origin probe, warning svstem
68. Remarks

69. During short term navigation high pressure oxygen and high oxidases are used and the use of water electrolysis is promising for future long term navigation
70. LiOH and KO<sub>2</sub> have already been used while others still need further research
71. Condensation is simplest especially in causing the moisture in the air to condense into drinkable water
72. Food regeneration has still not been realized and so must be carried from earth
73. Garbage storage: air exhaustor and ashing oven. Bioprocessing is not realized
74. It is necessary to consider the problem of bathing when navigation is longer than 2 weeks; dry cleaning is not satisfactory
75. Filtering and absorption: active carbon
76. Electrostatic processing
77. Combustion
78. Water; chlorination and absorption
79. Heat source: sun, equipment, people. Aside from the sun the others cannot be reduced and so must be used. Part of the excess heat is removed by the radiation and leaked gas
80. The chemical cell, fuel cell and solar energy cell have already been used
81. Instrument board, indication, communication
82. Item
83. Radiation shield
84. Safety and subsistence equipment
85. Attitude control
86. Physical
87. Cabin structure and materials
88. Life bag, lifesaving cabin, launch equipment and repair equipment
89. Automatic stabilization control and inertial cyclotron
90. Chemical
91. Food, fuel, oxygen, water
92. Emergency oxygen
93. Other
94. Equipment
95. Spacesuit
96. Manual control: jet reactor
97. Remarks
98. Redouble shield as much as possible
99. Even better predictions and equipment require strong research

Section Eight    The Spacesuit

In outer space there is no air or moisture and temperature changes are very great. If a person does not have protection when in outer space then he would not be able to survive. The spacecraft's airtight cabin is a sealed environment to protect human body life safely. Yet sometimes it is necessary for people to leave the spacecraft for movement and work. For example, when surveying and carrying out maintenance outside the airship cabin as well as observing while walking on the surface of the moon. In these types of situations it is necessary to wear specially made clothing called a spacesuit. In reality, the spacesuit is a movable airtight cabin. The spacesuit itself is sealed and within the suit are gas, pressure and temperature conditions to guarantee human body safety and comfort. When there is a mishap in the airship's system and human body safety is threatened the spacesuit is also a suitable life-saving device. An astronaut can leave the airship by means of the safeguard of a spacesuit.

The spacesuit is also called space airtight pressurized clothing and its design, construction and effect are required in the following situations: (1) when moving and working (including other celestial body surfaces) outside the cabin; (2) when there are breakdowns in the cabin's air regulation system or oxygen supply system; (3) when there is explosion decompression in the cabin; (4) when there is ejection lifesaving and falling into the water. In order to satisfy the requirements in various different situations the functions of the various spacesuits are not uniform. Yet, generally speaking, all require complex multilayered structures

and large amounts of necessary equipment and parts. Chart 6-4 shows the outside of various spacesuits and helmets. Numbers (1) and (2) have already been used and numbers (3) and (4) which use ball bearings to help joint movement should be used outside the cabin; another type uses aluminum foil for part of the outside to guard against small stony meteorites. In is now being used for experiments outside the cabin and movements on celestial body bases.

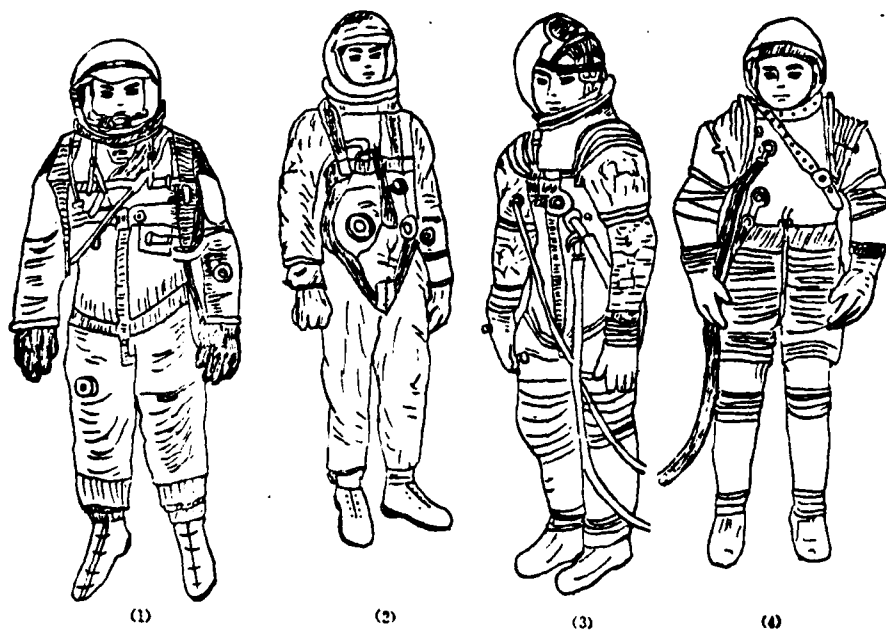


Chart 6-4 Airtight Spacesuit

Chart 6-5 shows the basic levels of this type of suit. The most basic requirements for the spacesuit are: (1) sealed, pressurization and oxygen supply; (2) after pressurization, the important moving parts of the body should not be too limited; (3) heat insulation must maintain warmth; (4) ventilation should disperse the heat; (5) anti-radiation and radiation heat; (6) guarantee good vision; (7) convenient to put on and take off; (8) have various types of equipment such as a communications system, oxygen supply system and a ventilation cooling system. Due to the many complex demands, the spacesuit has become a comprehensive specialized technology which requires the close cooperation of the departments of clothing material, sanitation, engineering, clothing technology and medical science. It developed from the sealed pressurized suit used in aviation and they still share a large number of common points.

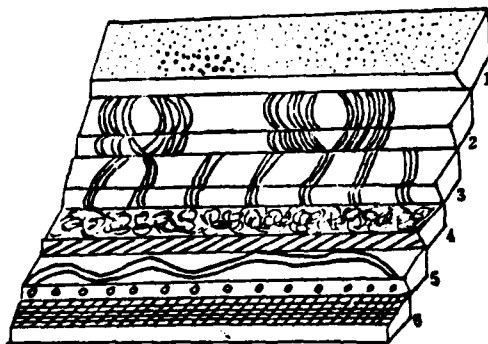


Chart 6-5 Schematic Chart of the Layers of an Airtight Spacesuit

Key, next page

1. Outermost layer, anti-radiation layer
2. Movement aid layer
3. Airtight pressurized limiting layer
4. Heat insulation layer
5. Circulation cooling layer
6. Layer next to the skin

#### 1. The Spacesuit's Pressurization and Supply of Oxygen

The air pressure in outer space is close to zero. When a person leaves the airship and enters outer space or the airship cabin loses its airtightness the air pressure will quickly drop and approach the vacuum conditions of outer space. In these situations, a person cannot maintain consciousness for more than 10 seconds and therefore must immediately pressurize the whole body and supply oxygen. The most important aim in developing an airtight suit is the resolution of this problem. The helmet and suit (including gloves and boots) can be made airtight automatically. In this airtight environment, the air pressure must be equal to the pressure of the repirated gases and the pressurized supply of oxygen is from the helmet. In order to decrease the air pressure in the suit and helmet and not have it differ too greatly from the outside pressure (the outside is nearly a vacuum and does not have air pressure), it is only necessary that the pressurization be limited to satisfying the oxygen pressure required by the human body wherein pure oxygen respiration is used and the pressure reaches to 152-160 millimeters on the mercury column. This type of low pressure pure oxygen respiration is not harmful to the human body and there is no great danger of fire. The larger the difference in pressure between the inside and outside of the suit the more

limited human joint movements are. When the difference reaches to over 160 millimeters on the mercury column, the limitation of joint movements can affect ejection lifesaving and other movements necessary for work. Therefore, oxygen pressure must be used which satisfies the needs of the human body, that is 152-160 millimeters on the mercury column. Moreover, only pure oxygen can be used. If the suit pressure and circulation make use of compressed air or nitrogen and the helmet (which cannot be separated from the clothing) uses compressed oxygen the problem of fire is greatly reduced. However, in recent years there are those who think that the pressure inside the spacesuit should generally be maintained above 200-380 millimeters on the mercury column.

The airtight suit's limited layer equipment cannot be separated from pressurization and is designed so that after pressurization there is excessive expansion of the limited airtight layer. It is installed above the airtight layer or joined to the airtight layer. Generally, it is the outermost layer of the entire suit. However, in order to reflect the solar heat radiation, the spacesuit also requires a white glossy outer garment which is generally made of titanium or aluminum wire and a blend of other materials; the outer garment is either joined to the spacesuit or worn independently. It is best for the airtight layer to be made of material which moisture can penetrate but not air.

## 2. The Spacesuit's Heat Insulation and Ventilation

In order to prevent the encroachment of cold (in outer space the stratosphere and two poles are shadowed by celestial bodies)

the spacesuit must have thermal insulation. The use of a layer made of thermal insulation clothing material was originally able to resolve this problem but a newly developed thermal material is still needed. Based on the special demands of the space navigation environment and emergency escape, the spacesuit's heat insulation requires 2-3 heat insulation units. If cotton material is used, the 2-3 heat insulation units are relatively thick and heavy. Therefore, the selection and development of a better and lighter heat insulation material is very essential. Titanium or aluminum cloth or a coating have the ability to reflect solar radiation heat but they can only be placed in the outermost layer of the clothing. Moreover, this type of reflection layer can affect the radiation heat diffusion of the human body and therefore wearing it for a long time is not necessarily beneficial.

The purpose of ventilation is heat diffusion and exhaust and it is in contradiction with heat insulation. Heat insulation prevents or decreases the encroachment of cold from the outside and at the same time also decreases the effects of the excessively high outside temperatures (decreases heat conduction).

In a narrow airtight suit the heat produced by the human body can raise the temperature under the clothing to an unendurable level within a short period of time. At the same time, the air moisture increases thus creating a high temperature, high moisture environment. If there are no artificial convection and evaporation measures taken, then human work efficiency and compensation will be negatively affected.



There are two methods of ventilation heat diffusion: one is open ventilation and the other is closed ventilation. The air of the former originates from an air blower or compressed air bottle. It enters the ventilated suit through a tube and after it circulates under the clothes it is sent out of the suit through another tube.

The amount of ventilation is determined according to the circumstances. For example, if the air that goes through the airtight pressurized suit reaches the body surface, the outside heat load is not high and the temperature of the air ventilation is 26°C then 100-200 liters of air is still required each minute. This enables the skin temperature to be maintained at 33°C and the sweat not to remain in the clothing. If the outside temperature is very high and there is a need for perceptual comfort then the amount of ventilation must be raised. The amount of ventilation is not only determined by the outside heat load but also differs according to air temperature, moisture, speed and body movement. The problems are certainly not simple. Among them the most difficult to resolve is the problem of the air source. This is not a great problem on earth but in an airship cabin the problem of load is substantial and if it is necessary for a person to bear it the problem is very large; when there is weightlessness or low weight the problem is not in weight but in volume.

Closed ventilation uses heat and water absorption equipment and materials and the air is continually circulated under the clothing towards this type of equipment by the ventilator. After the

air cools the water it flows back to the ventilated suit. At present, there is already miniaturized ventilation heat diffusion equipment which seems to have initially resolved the problems of weight and volume yet the ventilation cooling ability still needs to be further raised.

In order to further raise the heat diffusion abilities of the spacesuit, circulating water can be used instead of circulating air. Yet there are certain difficulties for the source of water in an outer space environment.

### 3. Design Requirements for the Helmet

An airtight helmet is a spacesuit component with a special structure and function. It must satisfy the following basic requirements:

1) It must be strong enough to endure pressure and cannot be too heavy. The outer shell is usually made of glass fiber reinforced plastic which can endure impact pressure and compression of 1.2 kilograms/centimeter<sup>2</sup>;

2) After being filled with air the neck should be able to move freely without strain;

3) The dead space in the helmet should be as small as possible, the absorption dead area should not exceed 500 milliliters and after closed air supply absorption the concentration of carbon dioxide should never exceed 1%;

4) When respiration valve resistance is small there should be no strain in respiration and no leakage of air and when it is

very cold outside there should be no freezing;

5) The telephone communication must have anti-noise disturbance and the voice clarity must be raised;

6) The front transparent section should be able to roll open;

7) The soft pad under the outer shell should be convenient for putting on and taking off the helmet;

8) The front must be transparent and guarantee the field of vision.

The last item mentioned above is very important and will be further explained below.

The helmet affects the amount of vision. For example, the transparent plate in the front part of the helmet must be placed on a frame and it is difficult for the edge of the frame not to limit the field of vision. However, most of the transparent plates used at present are very wide so that this type of effect is minimized.

The size, shape and transparency of the transparent plate is also related to the level of the limited field of vision. Here we will use two types of transparent plates for comparison. One is "V" shaped and the other is cylindrical. The limited field of vision of the former is greater. Chart 6-6 compares the original field of vision without wearing a helmet with the field of vision after wearing two types of helmets. After wearing the "V" shaped transparent plate helmet the field of vision became much smaller. This is naturally related to the diameter of the transparent plate. The cylindrical transparent plate shown in the chart is relatively large and therefore the field of vision is relatively larger.

The front transparent plates of present helmets have been greatly expanded so that there is no shrinking of the field of vision. This is not only the case when the head is stationary but it is also so when the head and eyes move. There are not many problems in wearing this type of helmet inside the cabin but we fear it is not suitable for movements outside the cabin in outer space.

If head movement is not limited and the shrunken field of vision can be compensated for then a dynamic field of vision can be obtained; a dynamic field of vision is much larger than a fixed field of vision. When the head turns and possibly sustains the airtight spacesuit filling with air the neck air bag expands and shoulder straps are limited by contraction. Therefore, the freedom of head movement becomes an index for appraising an airtight spacesuit.

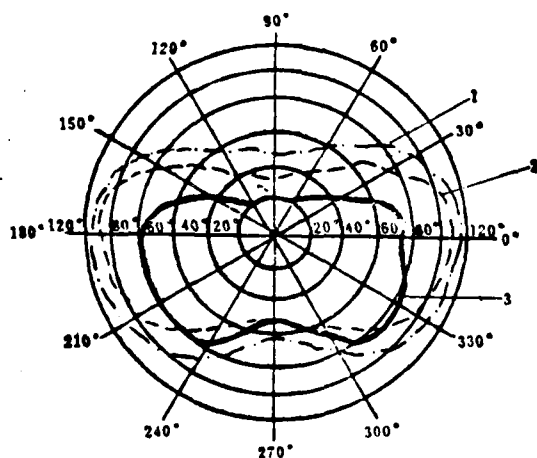


Chart 6-6 The Limitations of Two Types of Helmets on the Field of Vision

1. Helmet is not worn
2. Cylindrical transparent plate
3. V shaped transparent plate

The transparency of the transparent plate has an important effect on vision. On the one hand, the transparency of the transparent plate must rely on the transparent plate material but on the other hand it depends on the coarseness, density and arrangement of the transparent plate's electric heating wires. The former is generally no problem because at present a selection can be made from various plastics with very good transparency. The problems of the latter require further explanation. Because low temperatures can be encountered when moving outside the airship or during emergency escape, resistance wires are inserted between the two layers of the transparent plate and electric heating is prepared so as to prevent the exhaled vapour from freezing and obstructing the line of vision. This has already been effectively used in high altitude life saving. The space navigation emergency escape helmet must have this type of structure. The problem is selecting heating wires with the suitable thickness that can be installed properly so that when necessary they can very quickly raise the temperature of the transparent plate and thus avoid clouding and freezing. They can also prevent the heating wires themselves from obstructing the line of vision and lowering transparency.

The transparent plate's filtered light has a relatively large effect on vision, especially color vision. There is a great deal of

reference data in aviation engineering on the problem of filtered light which includes common filtered light and selected filtered light. Based on aviation experiences, at an altitude of 3,000 meters the light strength is about 12,000 feet-candle. When the astronaut has already sensed the need to decrease the light strength and the light strength has increased to 13,000 feet-candle in outer space, then it is even more necessary to decrease the light strength. Aside from this, although infrared and ultraviolet rays are invisible it is their strength that is too high. Since it is possible that they can burn the cornea and other structures in the eye, filtering must be used to weaken them. In order to realize these two goals it is very important to select suitable filter materials for the hood on the helmet's transparent plate. The hood covers the upper half of the transparent plate and is generally movable. When needed it can be pulled down with the hand and when not needed it is rolled up.

There are many kinds of filter hoods but they can be divided into two types: one is the color filter which filters various colors. Among them, the green solar lens can be penetrated by 25% of visible light, 5% of ultraviolet rays, less than 10% of infrared rays and a superficial amount of green color. It is satisfactory for use during high altitude flights. The other type is the intermediate filter, grey or metal plated filter reflecting plate. The amount of visible light, ultraviolet rays and infrared rays absorbed by the former is suitable for weak light but is not applicable for filtering large amounts of ultraviolet and infrared

rays. Among the many types of filters there are differences in performance so that the appropriate selection of a suitable filter to satisfy the demands for movement in outer space is a task that cannot be overlooked. Some people propose that the hood be constructed in two parts; the bottom part can be used for reading instruments and looking at close objects and be made from a more transparent filter while the upper part can be used to view distant objects and a less transparent filter can be adopted. The abilities of the two parts to absorb infrared and ultraviolet rays should be uniform and they should be able to absorb the greater part of these rays. The green solar lens seems to be able to satisfy most of these requirements yet it is not ideal for instrument reading and viewing close objects because it obstructs color discrimination.

#### Section Nine Medical Treatment and First Aid

##### 1. The Medical Treatment of Illnesses

The resolution of the medical treatment of illnesses for astronauts during long term and long distance navigation should be an unshirkable duty for aviation medicine and therefore the deployment of medical personnel, drugs and medical treatment health equipment become necessary measures. The specifics must be determined by the number of persons, time and distance of the navigation. The prevention of contagious diseases must be given special attention especially during the period prior to takeoff. Astronauts carrying contagious bacteria should not be allowed to board the airship. If the airship has not traveled far from earth during shorter navigation and an astronaut comes down with a serious illness the

ship can be inward bound at any time and dependable sanitation conditions can be increased inside the airship cabin. This can simplify the problem of medicine. It is only necessary to prepare medicines for common illnesses, medicines needed for emergency treatment and special drugs for space navigation to be able to satisfy the demands.

The following points are proposed based on the recommendations of experienced space navigation physicians:

1) A careful examination of the astronauts must be carried out prior to takeoff and those who are found to have problems are not allowed to board. All small illnesses should be treated beforehand and those carrying contagious diseases should absolutely not be permitted to board the ship. The substitute medicines used for those who are sensitive to certain drugs must be prepared beforehand. This should be discovered during ground tests and ground training. Preventative measures such as preventative inoculations and taking preventative drugs can be administered before the illness occurs. Astronauts should have a general knowledge of first aid, curing sickness and the use of drugs so that as soon as there is an illness they can handle it properly.

2) Anti-overweightness drugs should be considered for takeoff and return. There are three major types.

(A) There are three groups of blood vessel constricting agents:

(1) Those that effect different parts of the brain including blood vessel central stimulants such as pentazole,



strychnine, caffeine and phenacaine;

(2) Drugs that directly affect the adrenaline function of the blood vessel wall muscles such as adrenaline, noradrenaline, ephedrine and neo-synephrine;

(3) Drugs that directly affect the smooth muscles of the blood vessels such as hypertensors and pressors.

Clinical tests showed that the second group of drugs was better. Yet, in actuality, aidelong (?) is used more.

(B) Anti-anoxia agents: for example, glutelin (?).

(C) Drugs for when there is obstruction of the pulmonary blood vessels and blood pressure rises, there is decrease in internal secretion and the trachea expands such as atabrine type drugs. In recent years there are also people who have considered the use of drugs to prevent lung collapse.

3) The following problems should be considered when in weightlessness (during orbital flight):

(A) Drugs to prevent the cardiac blood vessel and hemato-logical effects of weightlessness such as blood vessel contraction agents and drugs to prevent cardiac muscle atrophy and promote cardiac metabolism - for example, glucose, lactose, pyruvate, digoxin and gaitai (?) ether; the latter two are good;

(B) Drugs for weightlessness that cause the metabolism rate to decrease such as stimulation protein compound drugs;

(C) Drugs for the physiological effects created by the destruction of the day and night rhythm;

(D) Drugs for raising work efficiency under weightlessness

such as miqidang (?) and amphetamine; among the two miqidang(?) is good;

(E) Drugs for space sickness (see previous section on motion sickness;

(F) Drugs for radiation injury (see previous section on protection against radiation);

(G) The use of drugs for surgical injuries, first aid and common illnesses.

Tables 6-9 to 6-11 give separate listings of the drug contents of the medicine kits and the conditions of the astronauts who became sick in the American Apollo 7-11 airships.

1 时 间	5 症 状	36 病 况	67 出现次数
2 航 行 前	6 轻度尿异常	37 未确定	3
	7 鼻炎、咽喉炎	38 单一性疱疹	2
	8 胃肠炎	39 沙门氏菌属感染	2
	9 胃肠炎	40 未确定	3
	10 痤疮	41 皮肤溢出	2
	11 腹部毛囊炎	42 未确定	1
	12 肾 病	43 霉菌孢子	1
	13 小腿脚	44 未确定	1
	14 脚 病	45 未确定	1
	15 齿髓炎	46 早已存在的齿病和龋齿	1
	16 流感症状	47 未确定	2
3 航 行 中	17 鼻 炎	48 未确定	3
	18 胃 炎	49 鹅口疮性溃疡	1
	19 恶心和呕吐	50 未确定	1
	20 恶心和呕吐	51 透肺性	1
	21 胃不适	52 透肺性	5
	22 面脚再现	53 接触性皮炎	1
	23 呼吸刺激	54 玻璃纤维	1
	24 眼刺激	55 玻璃纤维	1
	25 皮肤刺激	56 玻璃纤维	2
4 航 行 后	26 胃肠炎	57 可能系食物中毒	1
	27 轻度尿异常	58 未确定	1
	28 鼻炎、咽喉炎	59 流感B	1
	29 流感症状	60 流感B	1
	30 流感症状	61 未确定	1
	31 流感症状	62 流感A <sub>1</sub>	1
	32 齿髓炎	63 早已存在的齿病和龋齿	1
	33 充血性前列腺炎	64 未确定	1
	34 一侧鼻窦炎	65 未确定	1
	35 浆液性中耳炎	66 未确定	1

Table 6-9 The General Illness Conditions of Astronauts in the American 7-11 Apollo Airships

1. Time
2. Prior to navigation
3. During navigation
4. After navigation

5. Symptoms
6. Light urine abnormalities
7. Rhinitis and angina
8. Gastroenteritis
9. Gastroenteritis
10. Seat sores
11. Abdominal hair follicle inflammation
12. Ringworm of the arms
13. Ringworm of the shanks
14. Ringworm of the feet
15. Pulpitis
16. Flu symptoms
17. Rhinitis
18. Gastritis
19. Nausea and vomiting
20. Nausea and vomiting
21. Stomach discomfort
22. Ringworm of the face reoccurs
23. Absorption irritation
24. Eye irritation
25. Skin irritation
26. Gastroenteritis
27. Light urine abnormalities
28. Rhinitis and angina
29. Flu symptoms
30. Flu symptoms
31. Flu symptoms
32. Pulpitis
33. Hyperemia prostatitis
34. Nasal drip on one side
35. Media serosa
36. Condition of illness
37. Indefinite
38. Simple blister rash
39. Salmonella infection
40. Indefinite
41. Sebaceous overflow
42. Indefinite
43. Sporomycosis
44. Indefinite
45. Indefinite
46. Periodontosis and dental caries existed earlier
47. Indefinite
48. Indefinite
49. Thrush ulcer
50. Indefinite
51. Labyrinthine
52. Labyrinthine
53. Contact dermatitis
54. Glass fiber

55. Glass fiber
56. Glass fiber
57. Possible food poisoning
58. Indefinite
59. Flu B
60. Flu B
61. Indefinite
62. Flu A<sub>2</sub>
63. Periodontitis and dental caries existed earlier
64. Indefinite
65. Indefinite
66. Indefinite

项	目	存 量	项	目	存 量
2	1. 滴眼药 (1/4% 甲基纤维素)	0~2	16	13. 鼻渊剂	1~3
3	2. 压缩绷带	2	17	14. 阿斯匹林片	72
4	3. 包扎用品	12	18	15. 抗菌素片 (四环素250毫克)	15~20
5	4. 抗菌素药膏	1	19	16. 抗菌素胶囊丸 (氨基苄青霉素250毫克)	0~60
6	5. 皮贴	.1	20	17. 镇静剂胶囊丸 (速可眠100毫克)	0~21
7	6. 镇静剂注射剂 (杜冷丁100毫克)	3	21	18. 吸鼻剂	0~3
8	7. 运动病片	0~24	22	19. 抗组织胺剂丸 (苯海拉明50~100毫克)	0~8
9	8. 兴奋剂片 (苯丙胺 5 毫克)	12	23	20. 止痛片 (扑热息痛325毫克)	0~14
10	9. 运动病注射剂	3	24	21. 滴眼药 (1% 甲基纤维素)	0~2
11	10. 镇痛胶囊丸	12~18	25	22. 服药青杆菌肽	0~1
12	11. 降压片	24~60	26	23. 运动病片	0~12
13	12. 止泻宁片	24	27	24. 米利胃片	0~20

Table 6-10 Contents of Command Module Medicine Kit

1. Item
2. Eye drops (1/4 methylcellulose)
3. Compression bandage
4. Wrapping article
5. Antibiotic ointment
6. Sebaceous
7. Sedative injection (100 milligrams of duridrine(?))
8. Motion sickness tablets
9. Stimulants (amphetamine, 5 milligrams)
10. Injection for motion sickness
11. Analgesic capsules
12. Hypertension pill
13. Antidiarrheal pill

14. Quantity
15. Item
16. Nasal lubricant
17. Aspirin
18. Antibiotic pills (250 milligrams of tetracycline)
19. Antibiotic capsules (250 milligrams of amino benzyl penicillin)
20. Sleeping capsules (100 milligrams of secanol)
21. Nasal spray
22. Antihistamine pills (50-100 milligrams of diphenhydramine)
23. Pain killers (325 milligrams of paracetamol)
24. Eye drops (1% methylcellulose)
25. The eye ointment bacitracin
26. Motion sickness pills
27. Millikan(?) tablets
28. Quantity

1 项	目	5 存 量	6 项	目	10 存 量
2	止痛片	8	7	睡眠胶囊丸(迪可眠100毫克)	2
3	兴奋剂片(苯丙胺5毫克)	4	8	滴眼药(1%甲基纤维素)	1
4	阿司匹林片	12	9	压缩绷带	2

Table 6-11 Contents of Lunar Module Medicine Kit

1. Item
2. Antidiarrheal pill
3. Stimulants (amphetamine, 5 milligrams)
4. Aspirin
5. Quantity
6. Item
7. Sleeping capsules (100 milligrams of secanol)
8. Eye drops (1% methylcellulose)
9. Compression bandage
10. Quantity

## 2. Problems of Escaping Danger in a Desert, Polar Region and the Sea

If by chance there is a situation that is difficult to

overcome during space navigation then it is necessary to promptly inward bound. If there is trouble in inward bound, then another airship should be promptly sent to rescue it. During this process, the spacesuit and lunar module can be used as critical lifeboats. If the airship interior can no longer maintain life, then one can only eject out of the airship and await the other ship to come to the rescue. This type of rescue process is actually similar to rendezvous docking of airships in space.

The problem of escaping danger when an airship returns and falls into the ocean, barren hills, the desert as well as the north and south poles is worthy of serious attention. Here we will briefly discuss these situations in separate sections.

#### 1. Escaping from Danger in a Desert

If an astronaut drops down in a torrid desert the main dangers are thirst and high temperatures. Under the desert's scorching sun the human body sustains about 300 kilocalories of heat from the outside each hour. When the temperature is above 33 °C, the human body's conduction and radiation heat diffusion no longer function; the heat diffusion can only have perspiration evaporation. When the air temperature of the scorching desert is 37.8°C people can sweat and lose as much as 1 liter/hour. When stationary, water loss can be over 4 liters per day and when performing hard work it can be 8-10 liters per day. The total amount of water in the human body occupies 70% of its total weight. The average total volume of water of an adult is about 45 liters. On

the average a person drinks 1,200-1,500 milliliters of water per day and 300-500 milliliters of water are metabolized. When in the high temperatures of the desert there must be a large supply of water so as to compensate for the water lost through perspiration. Otherwise, there can be dehydration. When the human body water loss reaches 1-5% of the body weight there will be feelings of thirst, discomfort, nausea as well as a decrease in work efficiency; water loss of 6-10% of the body weight causes dizziness, headaches, respiration difficulties, a decrease in blood volume, a rise in blood cell concentration, a deficiency of saliva, unclear speech and an inability to walk. When water loss reaches 11-20% of the body weight this can cause delirium, twitching, deafness, blurry vision and finally result in death.

In order for a person weighing 70 kilograms to do effective work, water loss cannot exceed 4.5 liters. The physiological limitations of water loss are a 60% decrease of extracellular fluid and a 30% decrease of intracellular fluid. In other words, an insufficient supply of water in a desert area becomes a very serious problem for escaping danger. The resolution of this problem can be initiated from several directions. Because there is difficulty in the source of water the supply of water is not easily resolved. Below we bring forth several supplementary and auxiliary methods:

- (1) Think of a way of placing the body in a shadow so as to greatly decrease the loss of water;
- (2) Decrease activity as much as possible;



- (3) Economize on the use of water;
- (4) Eat less solids and semi-solids;
- (5) As far as possible move about during the evening;

We will further explain these auxiliary methods below. When a person is stationary in a shaded air temperature environment of 37-40°C and drinks 1-1.5 liters of water per day, within 2-3 days water loss can be maintained at 7-8%. If the air temperature is above 44°C and no activity is done while in a shaded area, water loss can reach 3.5 liters/day. When there is a lack of water, the amount of body water noticeably decreases and the urine concentration greatly increases. Therefore, in a very hot desert, water is an extremely important lifesaving material. However, when there is a water source deficiency, the only method is economizing on the use of water whereby the most scientific method for drinking water can be used. For example, if 1 liter of water is taken at one time 380 milliliters of it is excreted by the kidneys but if each time 83 milliliters is taken and each time is distributed in intervals over a certain period of time with the result that the same 1 liter is consumed only 80-90 milliliters is excreted by the kidneys. In this way the water can be fully utilized by the body.

When living in a very hot desert the effect is determined by water and not food. On the contrary, food can consume moisture so that high proteins and highly fatty foods should especially be eaten as little as possible and the consumption of food should be as small as possible; if one is completely without water then one should not eat at all; the more one eats the faster one dies.

If handled properly one can walk for two nights in the desert when the temperature is 26.7-32.2°C.

## 2. Escaping from Danger in a Tropical Ocean

Originally the huge waves of a tropical ocean were a serious danger but the excellent airtight spacesuits or design improved life rafts have made this danger secondary. Raising a tent on a life raft for shade is a very good anti-heat measure. When on an unshaded sunny high wind velocity ocean body, body water loss is very subjective. For example, when the air temperature is 25-27°C, the relative humidity is 76-65%, wind velocity is 0.5-1 meter/second and the body is in sunlight, 1-1.8 kilograms of water is lost through perspiration every 3 hours. Under the same conditions but with a tent covering water loss is only 0.6-0.8 kilograms. One of the advantageous conditions of the ocean's surface is that the wind is great, a second advantage is that ocean water can be used to moisten the body and clothes, and a third advantage is one can drink the water distilled by the scorching sun as well as the collected rain water. The fourth advantage is one can fish to allay one's hunger. Historically, it has been recorded that those who had accidents in aircraft, submarines and steamboats and fell into the water were able to float on the ocean for several tens of days in a lifeboat before being rescued. This signifies that with strong will, certain lifesaving equipment and a grasp of certain lifesaving techniques there is the possibility of maintaining life and successfully returning to land.

When on the ocean it is also necessary to be careful not to drink the ocean water. People who drink ocean water usually die earlier than those who do not. This is because the salt content of ocean water is very high and this causes an unbearable load on the urinary system. The kidneys can only bear electrolyte concentration that do not exceed 2%. In order to excrete the salt from 100 grams of consumed ocean water, it is not only necessary to excrete all of the moisture in the consumed ocean water but one must also lose 50 milligrams of body water. Because of this, the more ocean water consumed the faster the body dehydrates. If too much is consumed the kidneys will be unable to carry out acid salt equilibrium which will destroy the physiochemical balance in the body and cause damage to the central nervous system.

### 3. Lifesaving in Polar Regions

If an astronaut falls in a north or south pole region the main danger is low temperature. The emergency measures and main points for attention at this time are:

(1) Build a covered shelter as fast and as best as possible. Trees, ice and snow blocks can be used as building materials; a large snow drift can be dug into a dwelling. Furthermore, pieces of wood, dry moss and objects floating to the shore can be gathered and used for keeping warm.

(2) In order to keep warm one must prevent the clothes from getting damp. When working, one should take care to loosen their collar and appropriately wear less clothing so as to avoid perspiration moisture; if the clothes are too thick then an increased amount of energy will be used when working. When there is severe

cold the limb extremities are most susceptible to frostbite and thus ways must be thought of to keep them warm.

(3) One must avoid snow blindness when working in a snowy region. Snow blindness can not only occur during a clear sunny day but can also occur on a cloudy day. Sun protection glasses are used to overcome this. If one does not have protective glasses then cloth can be temporarily used to cover the eyes and only a small hole is made for seeing things.

### 3. The Life Bag

In order to prevent accidents from occurring, an astronaut should carry a life bag on his person. It is best for the life bag to include as many articles as possible, yet it cannot be excessively cumbersome. Generally, a life bag can only contain necessities to maintain life for 3-5 days. Principal among them are: (1) food; (2) water; (3) gathering or storage equipment; (4) ventilation equipment; (5) a small emergency case; (6) swim equipment; (7) articles needed for camping; (8) other necessary articles; (9) necessary equipment for self defense.

The water in the life bag must be disinfected and be able to be used for at least several days. A small amount of salt should also be packed so that it is convenient to drink weak salt water in the desert.

The small emergency case should have drugs and instruments for emergency injuries including commonly used drugs and drugs with wide curative effects such as wide spectrum antibiotics.

Communications equipment is extremely important and should include a miniature radio transmitter-receiver, a multipurpose plug, an electric source, signal lamp, signal reflector, a fluorescent light bulb, a radio navigation mark, an alarm and a signal flare.

The fishing, hunting and cutting equipment include fishing and hunting utensils as well as apparatus for climbing and cutting down trees (a saw and an ax).

The camping equipment includes wind resistant matches, highly effective fuel, sewing scissors as well as various types of all purpose small knives which can be used when going through a dense jungle. They can also be used as small shovels for digging out a dwelling. The parachute can have many uses such as material for a tent, a sleeping bag and clothing as well as for fishing and hunting apparatus.

Swim equipment is generally an inflatable float. It is best that it be a device that can resist cold when in cold water such the cold water life raft that protects against low temperatures. Generally, the spacesuit should be able to float on water and be water tight.

Food used for lifesaving should be able to be kept for a long time, at least several days without becoming spoiled and producing toxicit and it should be portable. Its food ration must be able to guarantee energy for 25-40% of human metabolic consumption, be enough for 3-5 days and be able to sustain certain work capabilities. Body weight will of course drop yet after several days after escaping danger it can be restored. The standard food ration

for lifesaving food is fixed at 1,500 kilocalories/day. In order to make allowances for possible water supply difficulties a good deal of carbohydrates should be included in the food. The food ration for maintaining life for 7 days can be lowered to only 4,000 kilocalories with a total weight of 800 grams wherein an average of less than 600 kilocalories are consumed each day. Table 6-12 is a designed plan for this type of lifesaving food ration.

1 天	4 补充电解质(毫当量)	13 碳水化合物食品(千卡)
2 第1天	5 氯化钠 150	14 无
2	6 碳酸氢钠 150	1000
3	7 碳酸氢钠 150	1000
4	8 碳酸氢钠 100	500
5	9 碳酸氢钠 75	500
6	10 碳酸氢钠 50	500
7	11 无 无	500
3 总计	12 钠 675	4000

Table 6-12 A Design Plan of Lifesaving Food Ration

1. Day
2. First day
3. Total
4. Supplementary electrolyte (milliequivalent)
5. Sodium chloride 150
6. Sodium bicarbonate 150
7. Sodium bicarbonate 150
8. Sodium bicarbonate 100
9. Sodium bicarbonate 75
10. Sodium bicarbonate 50
11. None
12. Sodium 675
13. Carbohydrate (kilocalories)
14. None

#### Section Ten The Night and Day Rhythm and the Biological Clock

The life activities of living organisms have a certain

periodic rhythm. Some of this periodic rhythm uses day and night as a period and is called day and night rhythm. For example, mice have strong activity at night and rest more during the day. Because of this, their various life activities are stronger at night than during the daytime; generally animals which come out during the daytime have stronger life activity during the daytime than at night. Other life activities use years or months as the period. For example, the menstrual cycle and the migration of birds. The periodic rhythm of life activities is similar to a clock and therefore some people call it the biological clock. Charts 6-7 to 6-9 show some examples of biological clock phenomena. It can be seen from these examples that the biological clock is a rather common phenomenon and is manifested in many forms.

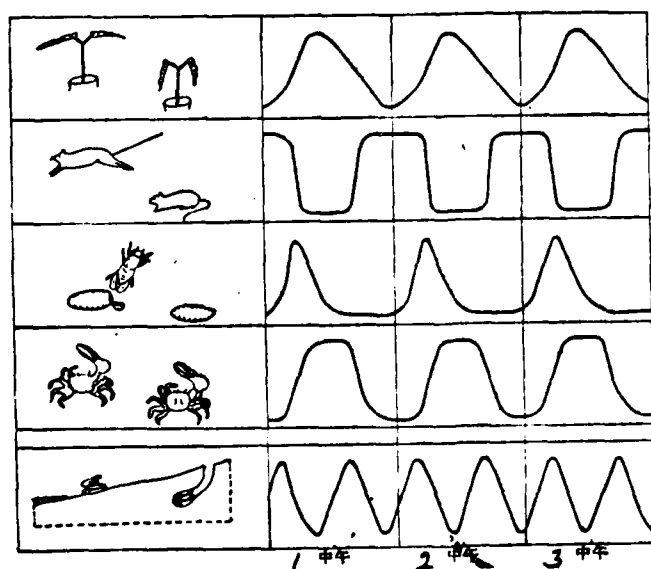


Chart 6-7 The Day and Night Rhythm of Some Biological Activities

1. Noon
2. Noon
3. Noon

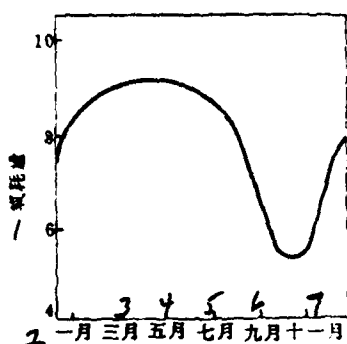


Chart 6-8 The Annual Rhythm of the Daily Oxygen Consumption of Potatoes During Three Years of Steady Growth

1. Oxygen consumption
2. January
3. March
4. May
5. July
6. September
7. November

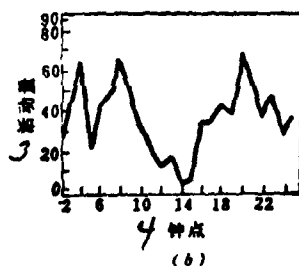
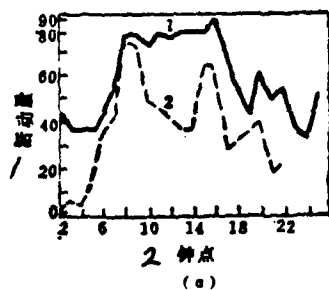


Chart 6-9 The Day and Night Rhythm of Dog (1) and Wolf (2) Movement Activities

1. Amount of movement
2. Hours
3. Amount of Movement
4. Hours



The various life activities of man also have periodic rhythms which are concretely manifested by the biological clock in the human body. Among them the day and night rhythm is the most obvious. For example, the pulse, respiration rate, body temperature, blood pressure, metabolism, skin electricity, blood and urine composition and even hair growth, changes in immunity and the biochemical process all have certain day and night rhythms. Charts 6-10 to 6-12 are several examples of the day and night rhythms of human body physiological functions. It can be seen from these examples that daytime activities are stronger than night activities. Although this is related to the living habit of more activity during the daytime, yet it is even more important that the biological clock of mankind gradually evolved over the last million years.

The biological clock and day and night rhythm are problems worthy of attention in aviation and space navigation because changes in the day and night rhythm of the natural world can be encountered in aviation and space navigation. For example, the night and day period of an airship in earth orbital flight changes according to its orbital altitude. For the orbital altitude of most earth orbiting airships which orbit the earth once every two hours, there is a great discrepancy with the normal 24 hour day and night rhythm. If flying toward the moon the day and night rhythm is also different than on earth. Thus an astronaut should understand that while living in an airship under artificial light the sense of day and night is lost but the day and night rhythm of the physiological functions do not change for a short time or only partially shift.

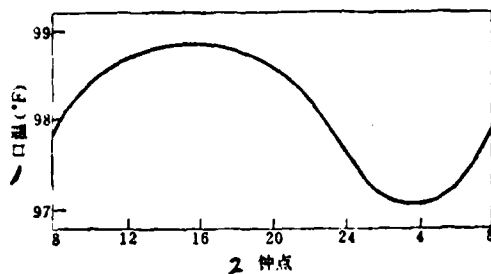


Chart 6-10 The Day and Night Rhythm of Man's Body Temperature

1. Oral temperature (°F)
2. Hour

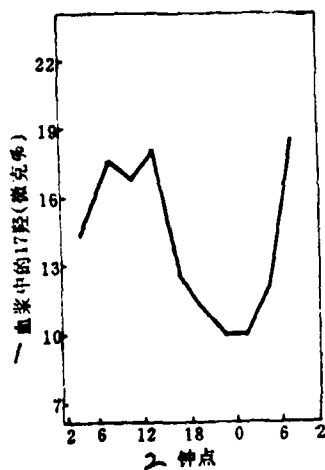


Chart 6-11 Day and Night Rhythm of 17 Hydroxyl in Human Blood

1. 17 Hydroxyl in blood (microgram %).
2. Hour

See next page for Chart 6-12

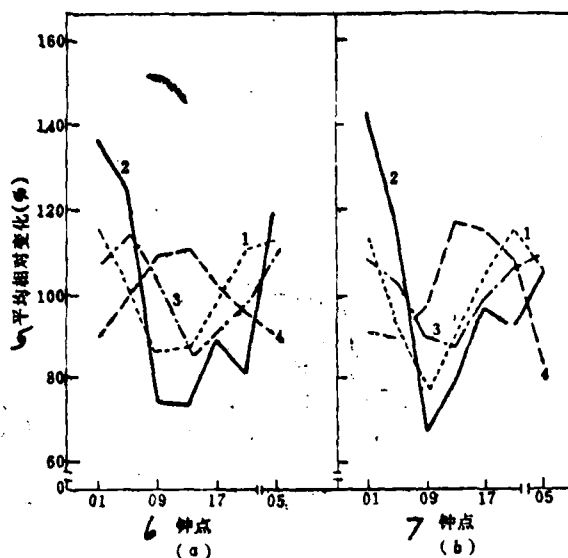


Chart 6-12 Day and Night Rhythm of a Human Hemogram

- Line 1 - Lymphoid cells
- Line 2 - Eosinophil
- Line 3 - Mononuclear cells
- Line 4 - Multinucleate cells
- a - % in blood serum
- b - % in comparison to red blood cells
- 5. Average relative change (%)
- 6. Hour
- 7. Hour

The intercontinental flights of modern supersonic passenger planes can have time shifts. For example, when flying from Peking to London the time goes back over 7 hours so that when Peking time is 7:45 A.M. London time is midnight; on the contrary, when flying the other way the time goes forward over 7 hours so that when London time is 12 o'clock noon Peking time is 7:45 P.M. If the navigation course is north-south then seasonal shifts are encountered. For example, when flying from Harbin to Canton in

February it was as if one goes quickly from winter to the end of spring and beginning of summer; on the contrary, when flying from Canton to Harbin it is like going from spring's end to a severe winter.

Without a doubt the changes in the day and night rhythm and seasonal shifts can cause the rhythm of the human body's physiological functions to be lost or become disordered thus affecting work efficiency and bodily health. This cannot be overlooked for the safety and work efficiency of aviation and space navigation. This can only be overcome by adapting in advance, arranging more proper rest during flight and providing certain stimulants and sleeping when necessary.

## CHAPTER TWENTY-THREE

### CABIN POLLUTION

#### Section One Preface

There is the possibility of various pollutions existing in aircraft and airship cabins which include those from the fuel, waste gases, electrical equipment, armaments, paint, furniture as well as plastic and rubber articles. Excrements from the human body including gases, perspiration, feces, urine and gastrointestinal tract gases are also sources of pollution. High altitude, high speed aircraft and airships utilize airtight cabins and the pollutants in the cabin are generally unable to escape outside. When they accumulate in the cabin these pollutions must be handled and resolved.

We will now separately explain the sources of pollution in aircraft and airships cabins within three fields:

1) That from high altitudes and outer space; for example, high altitude ozone, cosmic space radiation etc. The problem of radiation has already been discussed in part five and thus is omitted from this chapter.

2) That from aircraft and airships articles for use and equipment; including electrical equipment, armaments, fuel and waste gas.

3) That from the human body; including human body meta-

bolized gases, excrement and bacteria.

Among the harmful gases, ozone, carbon dioxide and carbon monoxide are the most important. Therefore, the following sections will separately discuss their harm to the human body and their mechanisms. The other pollutants will only be briefly introduced.

## Section Two    Ozone

Ozone ( $O_3$ ) is formed by oxygen being affected by solar ultraviolet rays and at the same time it is decomposed by the action of the ultraviolet rays and reduced to oxygen ( $O_2$ ). The concentration of ozone on the earth's surface is only 0.01 ppm (0.000001) and its greatest concentration can reach to about 11 ppm at an altitude of 27-30 kilometers. At altitudes higher and lower than this, ozone concentration gradually decreases. Its distribution is shown in chart 6-13. The distribution of ozone is also related to the earth's latitude and seasons (see chart 6-14).

See next page for chart 6-13

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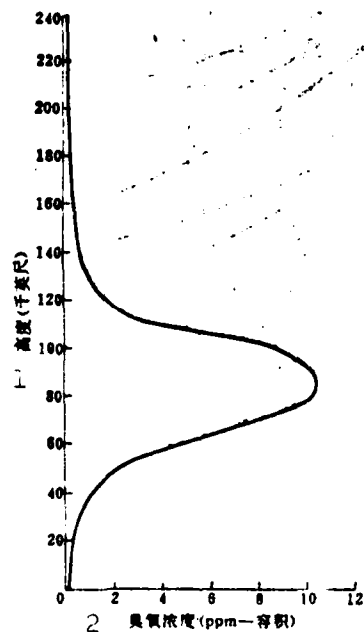


Chart 6-13 Ozone Concentration at Different Altitudes

1. Altitude (1,000 feet)
2. Ozone concentration (ppm-volume)

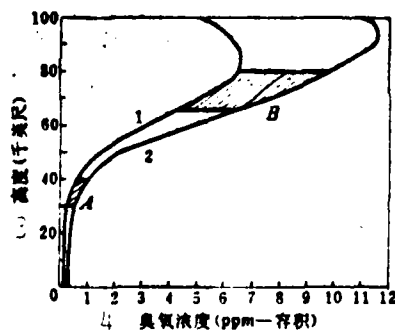


Chart 6-14 (Key on next page)

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Chart 14    The Relationship of Ozone Concentration to Geographical Latitudes and Seasons (Northern Hemisphere)

Line 1 - Autumn medium latitude

Line 2 - Spring high latitude

The two oblique line areas between the curves are:

A - The cruise altitude of modern jet aircraft;

B - The cruise altitude of supersonic transporters

3. Altitude (1,000 feet)

4. Ozone concentration (ppm-volume)

From chart 6-13 it can be seen that the ozone concentration reaches 8 ppm at an altitude of 18-21 kilometers which is about 20 times the allowable dose for continuous exposure for 2-3 hours. This type of concentrated ozone has certain danger for supersonic aircraft (flying at an altitude of 15-21 kilometers) and airships if cabin airtightness is not good or if compression of the surrounding atmosphere is used for the air supply. Chart 6-14 also lists the ozone concentrations encountered by modern fast aircraft cruising at high altitudes. It can be seen from this chart that aircraft cruising at high altitudes must pay special attention to ozone pollution. The corroding affect of ozone on rubber is very great and therefore has a destructive affect on rubber equipment in aircraft and airships. Ozone is the main pollutant at high altitudes and therefore it is necessary to explain its physiological and pathological effects.

1. Oxone Poisoning of the Respiratory System and General Clinical Symptoms

Ozone poisoning affects the respiratory organs and is most noticeable in the lungs. Research done on animals since 1857 has shown that when there is long exposure to ozone



concentrations exceeding 1-2 ppm this can cause serious pulmonary damage and even greater concentrations can cause death.

Long time exposure of the human body to an ozone concentration of 0.2 ppm can cause light pulmonary damage. Long time occupational exposure to 0.3-9.2 ppm ozone concentration can bring about pulmonum oedema, headaches and respiratory difficulties. Nine months after stopping exposure, fatigue and breathing difficulties are still not extricated but later there will be gradual recovery. Short time exposure to ozone (concentration is 0.6 ppm, exposure for 30 minutes) can produce respiratory tract irritation and exposure of 60 minutes causes a decline in the amount of respiration activity. With exposure of 120 minutes, the lung's ability to distribute carbon monoxide declines. Exposure of 60-150 minutes to 1.5-2.0 ppm causes the surplus air in the lungs to increase and the total lung volume, maximum quantity of breathing and amount of respiration activity to decrease. 120 minutes of exposure to 1.5-2.0 ppm produces mouth and throat dryness, localized pains below the thoracic cavity, a decrease in pulmonary activity and a lowering of concentration. Within 2 weeks after stopping exposure there is still fatigue, drowsiness, uncoordination in movements and disorderly speech. Exposure of 60 minutes produces noticeable pulmonum oedema. The threshold value of pulmonum oedema is in the concentration range of 4-5 ppm. Greater concentrations and longer exposure cause pulmonary alveolus permeability damage which is manifested in a decline of the oxygen distribution

coefficient. Further exposure to ozone causes serious pulmonum oedema, pulmonary damage and even threatens life.

The basic mechanism of ozone pulmonary damage is the action of ozone with pulmonary tissue protein which produces serious cell damage and causes changes in the permeability of cell membranes. This causes serious pulmonum oedema. Repeated use of ozone can also cause chemical pathological changes in the trachea and pulmonary alveolus fibers and a decline in the lung's ability to store air.

Chart 6-15 shows the concentration-time curves of ozone harm to the human body and illustrates that the higher the concentration and the longer the time the more serious the harm sustained by the human body. However, in airtight aircraft and airship cabins even though the ozone concentration outside the cabin reaches a level that can cause damage, the interior of the cabin is still perfectly safe. Naturally, if the cabin leaks gas or has a mechanical breakdown this is an entirely other matter.

See next page for chart 6-15

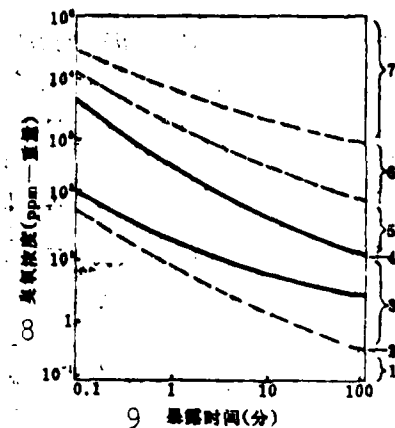


Chart 6-15 Ozone Damage to the Human Body

1. No symptoms area
2. Symptoms exist
3. Non-toxic area
4. Irritation reactions
5. Temporary damage area
6. Permanent damage area
7. Fatal area
8. Ozone concentration (ppm-weight)
9. Exposure time (minutes)

## 2. The Effect on the Eyes and the Sense of Taste

Ozone has noticeable negative effects on vision, sense of taste and sense of smell.

### 1. The Eyes and Vision

Ozone irritation of the eyes causes changes of the pressure in the eyes. After 28 subjects were exposed to 20, 30 and 50 ppm ozone concentrations for 3 and 6 hours, it was discovered that their fields of vision widened, night vision became poor and eye regulation and convergence weakened. After 6 hours of exposure there was eye inflammation and cornea dryness; this caused people to feel that their eyeballs were protruding out of their

sockets and there was also surface skin tension, fatigue and difficulty in concentrating their attention.

## 2. The Senses of Taste and Smell

1-2.5 hours of exposure to 1.2-6.0 ppm of ozone can cause impairment to the sense of smell. Ozone can also cause the human sense of taste to weaken.

## 3. Endurance to and Protection Against Ozone

### 1. Endurance

When resting or doing medium work, most people who are exposed to 0.75 ppm of ozone for 2 hours will have pains below the thoracic cavity, coughing and respiratory difficulties while a minority of people will suffocate. These symptoms can act as an endurance index for humans (see previous discussion of chart 6-15).

### 2. Safety Standards

Some foreigners have proposed that the maximum permissible concentration of ozone exposure during an 8 hour per day 5 day work week be 0.1 ppm. Because the exposure time of supersonic passenger planes is not long, the longest time for most passengers is 6-7 hours and the total annual exposure of a pilot is about 500 hours, the maximum permissible concentration of ozone is recommended as 0.2 ppm. When there is a minor breakdown of parts which causes the ozone concentration in the cabin to rise it is best that the permissible limit not exceed 0.3 ppm in 30 minutes. If there is a large breakdown the maximum concentration should not exceed 0.7 ppm in 60 minutes; or

1.0 ppm in 30 minutes; or 2.0 ppm in 10 minutes. Within the above mentioned time ranges the troubled aircraft must eliminate the breakdown or descend to a safe altitude so that the ozone concentration will decline to below 0.2 ppm.

### 3. Protective Measures

Although the toxicity of ozone is relatively great, protective measures are not very difficult. This is because:

(a) The airtight cabins of most aircraft and airships can prevent ozone from entering.

(b) Ozone easily decomposes under relatively high temperatures. For example, at an altitude of 24 kilometers a gas compressor is used to supply air in the cabin by compressing the surrounding air. At this time, because the air can reach to several hundred degrees after passing through the aircraft's engine compression within 1 second most of the ozone can be decomposed. Tests have shown that when compressed air is  $240^{\circ}\text{C}$  and  $150^{\circ}\text{C}$ , ozone decomposes to a level which does not harm the human body.

(c) Ozone can be made to decompose faster by using a catalyst; ram air is brought in front of the cabin and an ozone transformer can be added. If a nickel plated blade is used in the aircraft's or airship's transformer this can cause 95% of the ozone to disintegrate.

(d) A nickel or platinum filter can be used to filter the remaining ozone so that it is neutralized and does not have a toxic affect on humans. These measures are generally not dif-

ficult to realize.

### Section Three    Carbon Dioxide

#### 1. General Symptoms

Carbon dioxide is a gas produced by the combustion of organic material and is also a product of human metabolism. Carbon dioxide partial pressure and concentration is maintained at a certain level in human body respiration movement, the acid-base equilibrium of the blood serum and tissues. Its harmful effect is limited to when it is in very high partial pressure or concentration. If there is no carbon dioxide in the blood serum then normal human respiration and the acid-base equilibrium of the blood serum cannot be maintained. On the other hand, if the carbon dioxide concentration is too high then there can be a toxic effect. The carbon dioxide concentration in blood serum and tissues depends on the strength of the matter's metabolism, the carbon dioxide partial pressure in the air and the speed of pulmonary elimination. Common fresh air seems to have no carbon dioxide as the carbon dioxide mainly comes from tissue oxidation. One of the physiological functions of the lungs is the discharge of carbon dioxide; carbon dioxide can be quickly diffused by the pulmonary alveolus. Because of this, if the carbon dioxide concentration in the air exceeds the carbon dioxide concentration in the blood then it quickly enters the blood and raises the carbon dioxide concentration in the blood. When raised to a certain level this can cause symptoms of poisoning.

Generally speaking, the performance of medium work in an atmosphere where the carbon dioxide partial pressure is 8-15 millimeters on the mercury column does not cause any noticeable physiological obstructions. When medium and laborious work is done under a partial pressure of 21 millimeters on the mercury column some people have suffocation and chest pains (inter-costal pains). Most people who do medium work for 15 minutes when the pressure is 30 millimeters on the mercury column get headaches.

The symptoms brought on by exposure to different concentrations of carbon dioxide are shown in tables 6-13 and 6-14. It can be seen from the tables that breathing abnormalities occupy a leading position among the symptoms and that many of the symptoms are caused by hyperventilation. We will discuss these separately below.

1 二氧化碳浓度 (%)	2 主 要 症 状
0.033	3 正常大气压下无不良影响
1	4 呼吸加深, 潮气量增大30%, 对工作效率无明显影响
2	5 呼吸加深, 呼吸频率增高, 呼吸困难, 不舒服, 有负重感, 有时头痛, 腿脚
3	6 呼吸迫促, 脉率和动脉压升高, 嗜睡, 自我感觉不良, 一般虚弱、头痛加剧
4	7 呼吸困难, 意识活动显著降低, 工作效率明显下降
4.5~5	8 主诉不能忍耐
5	9 呼吸困难、紧迫, 剧烈头痛, 恶心, 呕吐, 可能发绀
6	10 呼吸更困难, 精神错乱, 呈发狂状态
7~9	11 动作失去协调, 10分钟内发生意识模糊
10~11	12 症状严重, 大部分人1小时内尚不致死亡, 但个别人3分钟内可致死亡
15~20	13 呼吸减弱, 血压下降, 昏迷, 反射消失
25~30	14 感觉丧失, 几小时后死亡

Table 6-13 Symptoms of Carbon Dioxide Poisoning (Total Air Pressure is 1 Atmospheric Pressure)  
(Key on next page)

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1. Carbon dioxide concentration (%)
2. Major Symptoms
3. No Negative effects under normal atmospheric pressure
4. Respiration deepens and the moisture content increases .30% which does not have any noticeable affects on work efficiency.
5. Respiration deepens, the respiration frequency rises, there is respiration difficulty, discomfort, a feeling of carrying a load, occasional headaches and drowsiness
6. Respiration quickness, rises in the pulse and arterial pressure, sleepiness, general weakness and intense headaches
7. Respiration difficulty and a noticeable decrease in conscious activity and work efficiency
8. The major symptoms are unendurable
9. Respiration difficulty, pressing, intense headaches, nausea, vomiting and possible temperature
10. Even more difficulty in respiration, mental disorders and the appearance of going mad
11. Movements uncoordinated and mental confusion within 10 minutes
12. The condition is serious. Most people do not die within 1 minute yet it can cause death in some individuals within 3 minutes
13. Respiration weakens, blood pressure drops, coma and reflexes are lost
14. Feelings of deletion and death within several hours

表6-14 二氧化碳不同浓度不同暴露时间下的症状

1 症状	5 暴露时间(分)和浓度(%)		
	6 10分	7 40分	8 80分
2 轻度生理功能亢进, 知觉变化, 轻度听力下降, 呼吸加快	2.0%	1.6%	1.4%
3 呼吸紧张, 臂力工作能力下降, 恶心, 头痛, 视觉辨别效率下降	3.5%	2.8%	2.4%
4 眩晕, 昏迷直至意识丧失	7.9%	6.8%	6.1%

Table 6-14 Symptoms Under Different Exposure Time to Different Concentrations of Carbon Dioxide

1. Symptoms
2. Light physiological hyperfunction, changes in perception, light hearing loss and quickening of respiration



3. Strained breathing, a decrease in mental work ability, nausea, headaches and a decline of visual discrimination
4. Vertigo, coma and loss of will
5. Exposure time (minutes) and concentration (%)
6. 10 minutes
7. 40 minutes
8. 80 minutes

## 2. Effects on Respiration

The respiratory reactions caused by carbon dioxide are mainly in respiration rate and moisture increases. This causes pulmonary respiration to sharply increase and corresponding rises of the carbon dioxide concentration in the pulmonary alveolus and arterial blood as well as the oxygen concentration (see table 6-15).

二氧化碳浓度 1 (%)	肺换气量增大 2 (%)	肺活量增大 3 (%)	潮气量增大 4 (%)	呼吸率增高 5 (%)	肺泡二氧化碳浓度升高 6 (%)	动脉二氧化碳分压升高 7 (%)
2		36				
3		56				
3.3	62					
4	120	118	53	40	13	10
5	200		88	60		14
5.4	210					
6	300		105	90		28
7.5	440		123	142		42

Table 6-15 The Effects of Carbon Dioxide on Respiration Functions

1. Concentration of carbon dioxide (%)
2. Increase in pulmonary breathing (%)
3. Increase in pulmonary activity (%)
4. Increase of moisture (%)
5. Rise of respiration rate (%)
6. Rise of pulmonary alveolus carbon dioxide concentration (%)
7. Rise of arterial carbon dioxide partial pressure (%)

### 3. The Effects on the Central Nervous System and Flight Capabilities

When the arterial carbon dioxide partial pressure rises, the thoracic blood vessels expand and resistance drops. When the carbon dioxide concentration in the air is less than 2.5%, the increase of the carbon dioxide concentration is helpful in overcoming the central nervous system symptoms caused by anoxia. Yet, excessively high carbon dioxide is not beneficial. Generally speaking, when the carbon dioxide concentration under one atmospheric pressure does not exceed 2%, it does not produce central nervous system symptoms and a decrease in work efficiency. When the concentration exceeds 3%, work efficiency begins to decline. Under a 3.3% concentration, a person's flash light critical fusion frequency lowers; the concentration increases to 4.5% and warning work efficiency noticeably worsens; when the concentration reaches 5% tracking control work efficiency begins to decline; when the concentration is over 7.2%, the tracking control work efficiency declines to a certain level.

If the total air pressure is greater than one atmospheric pressure, the carbon dioxide poisoning symptoms are mainly created by the carbon dioxide partial pressure. When the carbon dioxide partial pressure exceeds 25 millimeters on the mercury column, changes occur in the human electroencephalogram and work efficiency begins to decline. When the carbon dioxide partial pressure reaches 22 millimeters on the mercury column, endurance to physical work and overweightness weakens. For example, after living for several days in an environment where

the carbon dioxide partial pressure is 22-38 millimeters on the mercury column, human endurance to horizontal overweightness decreases by one-half.

#### 4. Endurance and Safety Limits

Chart 6-16 shows the effects of carbon dioxide on work efficiency and man's exposure time endurance limit to carbon dioxide. Many of the curves of the former fall below that of the latter which shows that concentrations which are much lower than the carbon dioxide endurance limit have a noticeable negative effect on man's work efficiency. Therefore, in order to guarantee good work efficiency and fighting ability, the carbon dioxide concentration should be maintained below curve (1) in the chart. It can also be seen from the chart that under one atmospheric pressure, man's endurance limit to carbon dioxide is in the area below 5% concentration. When in 6% carbon dioxide air (22°C) for 48 hours the main symptoms are anxiety, especially at night, an inability to concentrate on any work, easy excitability and restlessness. When working in 5-8% carbon dioxide air environment there were cases of individual fatalities. Chart 6-17 is a proposal for the limits and safety standards of human body discomfort reactions caused by carbon dioxide.

Generally, if working for 90 days the permissible limit of exposure to carbon dioxide concentration is 1%. In occupational exposure (working 8 hours per day), the maximum permissible limit of carbon dioxide is

proposed as 0.5%. During the Second World War the carbon dioxide maximum permissible limit for short time exposure under fighting conditions was fixed at 3%. However, in order to guarantee normal work efficiency, it is not beneficial for the carbon dioxide concentration inside the airship cabin to exceed 0.5-1%.

All of the above are situations under one atmospheric pressure conditions. Under different air pressure conditions, the carbon dioxide partial pressure for long time exposure should not exceed 4 millimeters on the mercury column. It is not beneficial for short time exposure to exceed 7 millimeters on the mercury column.

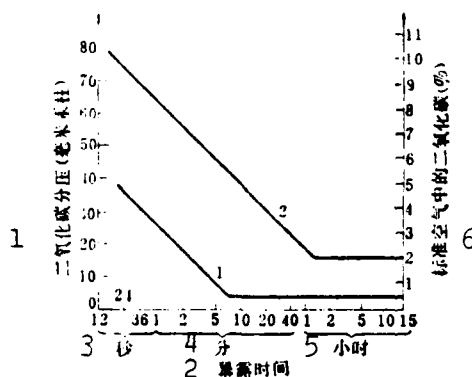


Chart 6-16 The Work Efficiency Limit (1) and Endurance Limit (2) to Carbon Dioxide (Key below)

When the carbon dioxide partial pressure is lower than curve 1 there are no noticeable effects on human work efficiency; when lower than curve 2 this can be endured by the human body.

1. Carbon dioxide partial pressure (millimeters on the mercury column)
2. Exposure time
3. Seconds
4. Minutes

5. Hours
6. Carbon dioxide (%) in standard air

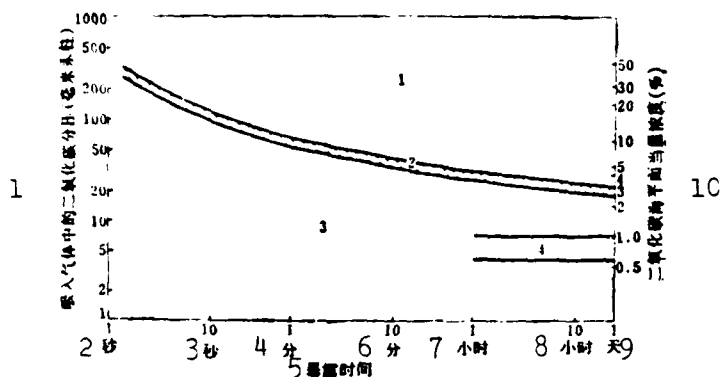


Chart 6-17 Endurance to Carbon Dioxide

- Line 1 - Carbon dioxide anaesthetized area
- Line 2 - Carbon dioxide endurance line
- Line 3 - Safety area
- Line 4 - Maximum permissible limit of long time exposure to carbon dioxide

1. The carbon dioxide partial pressure (millimeters on the mercury column) in inhaled gases
2. Seconds
3. Seconds
4. Minutes
5. Exposure time
6. Minutes
7. Hours
8. Hours
9. Days
10. Equivalent concentration (%) of carbon dioxide on the ocean's surface

#### 5. Factors Affecting Endurance to Carbon Dioxide

Human endurance to carbon dioxide is affected by many factors. Here we will only introduce the major ones:

1. Habituation

For example, subjects are allowed to live for 3-6 days

in air with 21% oxygen and 3% carbon dioxide and later their reactions are tested to even higher concentrations. Because of habituation, the respiration reactions of the subjects caused by carbon dioxide are lighter, so the main symptoms such as the stabilization of hand movements, alphabet letter drawing and changes in the electroencephalogram are lighter. According to reports, when humans live for 42 days in an environment with 1.5% carbon dioxide after the 23rd day there can be produced a compensatory acid-base equilibrium reaction. Because of this compensation reaction the physiological effects caused by the carbon dioxide gradually stabilize or decrease.

## 2. Ascension Rate of the Carbon Dioxide Concentration

When the carbon dioxide concentration ascends slowly endurance is high. For example, if someone suddenly enters air that contains carbon dioxide that registers 35 millimeters on the mercury column they can only endure this for several minutes. However, when a method is adopted to gradually raise the carbon dioxide partial pressure, for example, a rise of 7-10 millimeters on the mercury column per hour then the person can endure this for 3-4 hours doing medium work and even longer when resting. Another example is when the carbon dioxide is gradually increased to 5% within 32-37 hours the oxygen is gradually decreased to 12% and the total exposure time is 50-72 hours there are no noticeable effects observed on work efficiency. On the contrary, when the carbon dioxide concentration suddenly rises to 5% within a short period of time work efficiency noticeably declines.

### 3. Oxygen

Under high pressure oxygen conditions, if accompanied by a relatively high carbon dioxide concentration then there is a stronger tendency for oxygen poisoning.

### 4. Cold

Cold can cause endurance to carbon dioxide to decrease. For example, if a subject remains for 75 minutes in a 5°C environment within a 30-60 minute period 6% carbon dioxide is inhaled. This results in a decrease in shivering caused by the cold, an inhibition of the rising of the metabolism rate and a substantial drop in anal temperature. The pulse rate rises and increased in respiration caused by carbon dioxide are even more noticeable than under normal temperatures. At this time, subjective perceptions are warmer than not having inhaled carbon dioxide. When 4.5% carbon dioxide is inhaled the above mentioned effects are smaller and when 2.5% the above mentioned physiological reactions are minute.

## Section Four Carbon Monoxide

Carbon monoxide commonly called "gas" is the toxic gas often seen in propeller aircraft, airships and jet planes. In daily life, carbon monoxide comes mainly from coal furnaces, gasoline internal combustion engines and gasoline powered equipment.

A normal human body continually produces and eliminates small amounts of carbon monoxide. It is produced from the decomposition of glucose; each hour about 0.5-1.5 milliliters

is eliminated or about 10-30 milliliters per day. If on the average each person occupies 1-2 meters of space then after living in an airtight cabin for 5 days the carbon monoxide concentration inside the cabin can reach to over 50 ppm. This is the maximum permissible concentration for 90 days of constant exposure. It can be seen from this that human body elimination of carbon monoxide and its accumulation in the airship is a problem which cannot be overlooked for cabin sanitation.

The effect of carbon monoxide on the human body is mainly in the decrease of the blood's ability to transport oxygen. When there is severe poisoning central symptoms are prominent. These will be discussed below.

1. Carbon Monoxide Weakening of the Blood's Ability to Transport Oxygen

Carbon monoxide's affinity to haemoglobin is 240 times greater than towards oxygen and moreover it is very difficult to separate it from haemoglobin. After carbon monoxide is inhaled, the haemoglobin is immediately combined with the carbon monoxide and thus oxygenation ability is lost. At the same time, they join very closely unlike when oxygen and haemoglobin combined wherein the oxygen is easily separated. In this way it occupies the haemoglobin which can send oxygen. In other words, this decreases the blood's ability to send oxygen. It also hinders the blood's ability to send out carbon dioxide from the tissues. Serious carbon monoxide poisoning can be determined from the concentration of carbon monoxide haemoglobin (HbCO is an abbreviation for carbon monoxide haemoglobin). The higher



the concentration of carbon monoxide haemoglobin the lower the blood's ability to transport oxygen and carbon dioxide. This causes anoxia and an imbalance of the acid-base equilibrium.

The concentration of carbon monoxide haemoglobin in the blood is determined by the concentration of carbon monoxide, exposure time, pulmonary breathing ability and air pressure of the inhaled air as well as the concentration of carbon monoxide haemoglobin originally in the human body. The only major contradiction is in the weight of the inhaled carbon monoxide.

Normal people produce a small amount of carbon monoxide from the normal metabolic process in the human body. The carbon monoxide concentration in a male's blood reaches 0.38%, a female's 0.30% and the carbon monoxide haemoglobin content is 0.8%. The carbon monoxide content among smokers can reach 4% and a minority of people can have a bit higher. When the concentration of carbon monoxide in the surrounding air is lower than the balanced concentration of carbon monoxide in the blood the human body eliminates carbon monoxide through exhaled gases which causes the carbon monoxide and carbon monoxide haemoglobin in the body to decrease but the action is relatively slow. For example, when a smoker breathes pure oxygen for 6 hours under 7,000 meter altitude air pressure the carbon monoxide haemoglobin in his body decreases from 5.8% to 0.8%. On the contrary, when the carbon monoxide concentration in the surrounding air exceeds the carbon monoxide balanced concentration in the human body, the carbon monoxide in the air can be diffused in the body

and thus the carbon monoxide concentration and carbon monoxide haemoglobin in the body will gradually rise to a new equilibrium. The time the carbon monoxide is inhaled from the air and reaches a certain concentration in the body depends on the initial concentration of carbon monoxide in the blood, the concentration in the air as well as the person's activity and amount of pulmonary breathing. When stationary the time required for a 50% equilibrium concentration of carbon monoxide haemoglobin in the blood is about 3 hours. The time the carbon monoxide is eliminated from the body generally also depends on the same factors mentioned above but the level is of course lower. The relationship between the concentration, air pressure, exposure time of carbon monoxide in the air and the carbon monoxide haemoglobin in the blood is shown in table 6-1

1 周围空气中的一氧化碳浓度 (毫克/米 <sup>3</sup> ) (ppm)		2 碳氧血红蛋白含量 (%)		
		3 暴露 1 小时	4 暴露 8 小时	5 暴露 24 小时
12	10	0.4	1.4	
23	20	0.8	2.8	
35	30	1.3	4.0	
70	60	2.5	8.7	
117	100	3.6	12.9	

● 无限长时间暴露下的数值。达到此值以后，即使暴露时间再长，碳氧血红蛋白的百分比也不增加。

Table 6-16 The Relationship of the Concentration and Time to Carbon Monoxide and the Carbon Monoxide Haemoglobin Content

Concentration of carbon monoxide in the surrounding air (milligrams/meter<sup>3</sup>)  
Carbon monoxide haemoglobin content (%)

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3. Exposure for 1 hour
4. Exposure for 8 hours
5. Equilibrium value F.N.
6. F.N. The numerical value under an unlimited length of time. After attaining this value even if the exposure time is long again the percentage of carbon monoxide will not increase again.

## 2. General Symptoms and Their Effects on Flight Capabilities

The main symptoms of carbon monoxide poisoning are headaches, nausea, vertigo, paleness, unclear consciousness, collapse and even death. Generally speaking, the volume of carbon monoxide in the air is 0.02% and after 2-3 hours of exposure this can cause light symptoms of poisoning. See tables 6-17 and 6-18 for the relation of carbon monoxide concentration and poison symptoms. Clinically, the appearance of a "cherry red" color in the oral mucous membrane indicates that the carbon monoxide haemoglobin concentration has reached 40%.

1 吸入气体中一氧化碳容积 百分比(%)		2 中毒症状
0.02	3	2~3小时后可能引起额部轻微头痛
0.04	4	1~2小时后出现额部头痛和恶心, 2 1/3~3 1/2小时以后枕部头痛
0.06	5	1小时暴露, 出现头痛、恶心
0.08	6	3/4小时内出现头痛、眩晕和恶心。2小时内发生虚脱、意识不清
0.16	7	20分钟内出现头痛、眩晕和恶心。2小时内发生虚脱和意识不清, 可能死亡
0.32	8	5~10分钟内出现头痛、眩晕。30分钟内出现意识不清, 有死亡危险
0.64	9	1~2分钟内出现头痛、眩晕。10~15分钟内意识不清, 有死亡危险
1.28	10	瞬间效应, 在1~3分钟内出现意识不清和死亡危险

Table 6-17 . General Symptoms of Carbon Monoxide Poisoning

1. Volume of carbon monoxide in the inhaled gases (%)
2. Poison symptoms
3. Slight frontal headaches can arise after 2-3 hours
4. Frontal headaches and nausea can occur after 1-2 hours and occipital headaches after 2 1/3-3 1/2 hours

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5. Headaches and nausea after 1 hour of exposure
6. In 3/4 hour there appear headaches, vertigo and nausea. Collapse and unclear consciousness occur within 2 hours
7. Headaches, vertigo and nausea appear within 20 minutes Collapse, unclear consciousness and possible death occur within 2 hours
8. Headaches and vertigo appear within 5-10 minutes. Unclear consciousness and the danger of death occur within 30 minutes
9. Headaches and vertigo occur within 1-2 minutes. Unclear consciousness and danger of death occur within 10-15 minutes
10. Instantaneous effects. Unclear consciousness and danger of death occur within 1-3 minutes

1 一个大气压下一氧化碳浓度 (ppm)	2 碳氧血红蛋白 (%)	3 效 应
400	7.2	4 轻微
800	14.4	5 头痛, 用力时呼吸停止
1600	29	6 迷糊, 用力时虚脱
3200	58	7 失意识
1000	72	8 深度昏迷
4500	81	9 立即死亡

Table 6-18 Chronic Symptoms of One Hour Exposure to High Concentrations of Carbon Monoxide

1. Concentration of carbon monoxide under 1 atmospheric pressure
2. Carbon monoxide haemoglobin (%)
3. Effects
4. Minute
5. Headaches, respiration stops when exerting oneself
6. Blurriness, collapse when exerting oneself
7. Loss of consciousness
8. Deep coma
9. Instant death

The effects of carbon monoxide on flight capabilities appear early in affecting mental calculations and certain complex intellectual activities. When carbon monoxide poisoning reaches 2-5% carbon monoxide haemoglobin in the blood there begins to

appear a decrease in work efficiency. When the carbon monoxide haemoglobin reaches 4%, visual discrimination ability begins to decline. Other visual effects generally begin when the carbon monoxide haemoglobin is above 5%. When the carbon monoxide haemoglobin is above 15-20% there are headaches, obstruction to motor coordination and a decline in visual work efficiency. This can be considered the critical numerical value of the serious effects on flight capabilities.

### 3. Endurance and Safety Limits

#### 1. Endurance

Three minutes of exposure to a 1.28% carbon monoxide concentration is fatal to humans and 3 minutes of exposure to a 0.64% concentration causes incapacitation. The threshold value of carbon monoxide poisoning which results in blurriness and collapse is a 30% concentration of carbon monoxide haemoglobin. The general symptoms of endurance to carbon monoxide poisoning and the safety levels shown in tables 6-19 to 6-21 exceed this level. Therefore, these numerical values can only act as reference.

1 一 氧 化 碳 浓 度		3 暴露至虚脱的时间(分)
2 百分比 (%)	ppm	
20	$2 \times 10^5$	0.5
10	$1 \times 10^5$	1
1	$10^4$	10
0.33	3300	30
0.17	1700	60

Table 6-19 The Time Exposure to Carbon Monoxide Causes Blurry Consciousness and Collapse (The final concentration of carbon monoxide haemoglobin reaches 30% and the surrounding air pressure is 1 atmospheric pressure). (Key on next page)

1. Carbon monoxide concentration
2. Percentage (%)
3. Exposure time (minutes) resulting in collapse

1 暴露方式	5 空气中含量 (ppm)
2 职业性暴露 (8小时/天, 每周5天)	100(最高允许限) 6
3 职业性暴露 (8小时/天, 每周5天)	50
4 社会性暴露	20

Table 6-20 Safety Limit of Carbon Monoxide Under One Atmospheric Pressure

1. Type of exposure
2. Occupational exposure (8 hours/day, 5 days per week)
3. Occupational exposure (8 hours per day, 5 days per week)
4. Social exposure
5. Content in air (ppm)
6. 100 (highest permissible limit)

1 症状和限度	6 暴露时间(分)和浓度(%)	
	10分 7	60分 8
2 虚脱和死亡危险	0.60	0.15
3 头痛、眩晕、恶心	0.20	0.045
4 飞机上最大允许限度(美国空军规定)	0.08	0.01
5 飞机上最大允许限度(英国空军规定)	0.015	0.01

Table 6-21 Carbon Monoxide Poison Symptoms and Safety Limits

1. Symptoms and limits
2. Collapse and danger of death
3. Headaches, vertigo, nausea
4. Maximum permissible limit on an aircraft (U.S. Air Force stipulations)
5. Maximum permissible limit on an aircraft (British Air Force stipulations)
6. Exposure time (minutes) and concentration (%)
7. 10 minutes
8. 60 minutes

## 2. Safety Standards

The maximum permissible concentration of carbon monoxide for occupational exposure 8 hours per day is 0.01% (see table 6-20). In fighter planes it is not good for the carbon monoxide haemoglobin in the blood to exceed 12%. In 90 days of continuous exposure, the maximum permissible dose is 50 ppm. All of the above are safety standards under one atmospheric pressure. It has been proposed that under different air pressures the safety standard for the carbon monoxide haemoglobin concentration not exceed 4%. Yet, under normal conditions smokers exceed this level and thus these numerical values only provide a reference.

### Section Five    Aircraft and Airship Cabin Pollution

There are many types of aircraft and airship toxic substances and their origins are complex. Here we will only introduce those closely related to cabin sanitation.

#### 1. Those Produced from Electrical Equipment

Electrical equipment can produce ozone and carbon monoxide. Aside from these, if the equipment and insulating materials sustain too much heat then the surface material volatilization, combustion or explosion can all produce harmful substances and gases such as halogen, sulphur and nitrides. It is said that over 56% of the poisonous substances and gases in an aircraft come from the radio equipment.

#### 2. Fire-Extinguishing Agents

The most common is carbon tetrachloride and when heated

it produces toxic phosgene. At present, there are already other improved substances such chlorobromo-methane, trichlorobromo-methane, difluorodibromomethane or anydrous sodium carbonate. However, the heat decomposition substances of these materials are also very harmful (see table 6-22).

1 可产生毒性物质的物质	5 分 解 产 物
2 四氯化碳	6 氯化氢、氢和光气
3 氯溴甲烷	7 除上述物质外, 还有溴化氢、溴及溴化碳酰
4 溴化甲烷	8 溴化氢、溴、溴化碳酰

Table 6-22 The Toxic Substances and Decomposition Products in a Fire Extinguisher

1. Substances produced by toxic materials
2. Carbon tetrachloride
3. Chlorobromomethane
4. Methyl bromide
5. Decomposition products
6. Hydrogen chloride, hydrogen and halogen
7. Besides the above mentioned substances, there are also hydrogen bromide, bromine and carbon bromate
8. Hydrogen bromide, bromine and carbonyl bromide
3. Lubricants and Cleansers

The lubricant's heat oil vapour contains formaldehyde, acetaldehyde, panaldehyde, acrolein and cleaning agents used to clean the oxygen bottles and the trichloro ethylene in the air all of which are harmful.

#### 4. Refrigerants

At present, the most commonly used are several types of freon (freon 12 and freon 11<sup>4</sup>). Although they are not poisonous themselves yet many of the decomposed products are very harmful. Ethylene glycol is also harmful.



## 5. Batteries

If the lead piece used is not pure and contains arsenic and antimony then because of the effect of the hydrogen this can separately produce very strong toxic arsine and stibine.

## 6. Rocket Propellants and Waste Gases

This includes many types of harmful substances and gases; because there are so many types of propellants many kinds of harmful substances and gases can be produced. Fortunately, the airtightness of the airship cabin is excellent and it is not likely to allow large amounts of these types of harmful substances and gases into the cabin. For this reason, we will not list them individually but only the waste gases eliminated by a propeller aircraft are listed in table 6-23 as an example.

1 成 分	5 含 量 %	6 成 分	10 含 量 %
2 一氧化碳	2.8	7 氮	83.8
3 二氧化碳	10.8	8 氧	1.2
4 烃	0.7	9 氢	0.7

Table 6-23 Composition of Waste Gases Eliminated From a Propeller Aircraft

1. Composition
2. Carbon monoxide
3. Carbon dioxide
4. Hydrocarbon
5. Contents %
6. Composition
7. Nitrogen
8. Oxygen
9. Hydrogen
10. Contents %

## 7. Rubber and Plastic

Among the more than 100 types of commonly used chemical

compound products, plastic produces the most substances with toxic gases under high temperatures.

#### 8. Paint

Acrylic ester paint produces fewer poisonous gases than polyvinyl acetal and epoxy. Phenol formaldehyde resin can produce large amounts of formaldehyde and sometimes the concentration can reach 2 ppm.

#### 9. Armaments

Armaments are also one of the main origins of toxic gases. Table 6-24 lists some of these toxic gases.

1 有毒气体成分	1050 号 机 枪		15 7.62 厘米 炮		20 火 箭	
	11 平均	14 最大	16 平均	17 最大	21 平均	22 最大
2 二氧化碳	390	1700	400	680	2800	7900
3 阿莫尼亚	5.7	14	12	33	10	25
4 二氧化氮	6.0	1 例	20	25	23	未发现
5 氰化氢	0.4	1.0	10	1.2	5	10
6 氯	0.2	0.5	0.8	2.0	2	3
7 乙醛	2.3	10	2.0	1 例	24	未发现
8 氯化氢	12	未发现	18	未发现	—	4.0
9 二氧化硫	13	同上	19	同上	—	3.0

25 注：表内数值的单位为1000倍之值。即是在一氧化氮浓度为1000ppm下，该成分的气体浓度的ppm值。

Table 6-24 Examples of Aircraft Armaments that Produce Toxic Gases

1. Composition of toxic gases
2. Carbon dioxide
3. Ammonia
4. Nitrogen dioxide
5. Hydrogen cyanide
6. Cyanogen
7. Acetic aldehyde
8. Hydrogen chloride
9. Sulphur dioxide
10. No. 50 machine gun
11. Average
12. Not yet discovered
13. Same as above

14. Maximum
15. 7.62 centimeter gun
16. Average
17. Maximum
18. Not yet discovered
19. Same as above
20. Rocket
21. Average
22. Maximum
23. Not yet discovered
24. Not yet discovered
25. Note: the unit values in the table are 1,000 times that value. That is in a 1,000 ppm concentration of carbon monoxide the ppm value of the compositions gas concentration

The harmful gases and steam often seen in aircraft and airships are summed up in table 6-25.

1 化合物种类	11 毒物来源	21 毒性作用	31 毒物存在的特征
醇类 2	防冻液, 燃料, 高压液的组成 (酒精, 甘油) 12	抑制作用, 刺激眼和呼吸道; 视力障碍 22	醇的气味, 眼和喉头的刺激 32
醛和酮类 3	滑油分解产物或在高温影响下形成的烟内, 高压液的组成内 13	刺激眼和喉头; 抑制作用 23	香蕉油气味, 刺激喉头 33
芳香族碳氢化合物 4	马达和采暖装置所用的汽油或其他燃料中, 涂料中, 高压液系内 14	经皮肤或肺吸入引起抑制, 贫血, 恶心, 头痛, 白血球减少 24	排出气 (汽油) 味 34
二氧化碳 5	灭火器内, 废气或烟的组成, 干冰 15	呼吸加快, 喘息, 当空气中浓度到10%时意识丧失 25	没有气味, 喘息, 刺激眼和喉头 35
一氧化碳 6	烟和废气内 16	头痛, 头晕, 意识不清, 突然发生意识丧失 26	没有气味, 在座舱内有废气或烟出现, 间接指出其存在 36
四氯化碳 7	灭火器混合物中 17	受热作用形成光气, 引起头痛, 头晕, 休克和眼的刺激 27	新割下的干草味, 刺激眼和呼吸道 37
氯溴甲烷 $\text{CH}_2\text{ClBr}$ (129.40) 8	灭火器混合物中 18	抑制和刺激作用 28	弱的氯仿气味 38
乙二腈及其衍生物 9	冷却液, 高压液的组成 19	吸入有轻微的微毒作用 29	没有气味, 但某些分解产物具有热脂肪气味 39
乙基液 10	汽油添加剂 20	失眠, 精神不安, 多梦, 幻觉和运动失调 30	根据汽油味道判断其存在 40

Note: See page 256 for second part of Table 6-25

Table 6-25 The Harmful Gases and Steam that Frequently Appear in Aircraft and Airship

1. Type of chemical compound
2. Alcohol type
3. Aldehyde and ketone type
4. Aromatic hydrocarbon

41 化合物种类	46 毒物来源	51 毒性作用	56 毒物存在的特征
溴甲基 42	灭火器混合物中含有 47	抑制作用, 视觉和语言障碍, 意识混乱 52	有弱的令人欣慰的气味, 与火接触形成刺激性气体 57
氯甲基 43	冷却剂 48	头痛、头晕和恶心、意识混乱、痉挛等 53	刺激作用, 遇火形成盐酸 58
二氧化氯 44	在废气和烟火(弹药)中含有 49	刺激眼和呼吸道 54	强烈刺激性, 咳嗽, 刺激眼和喉头 59
二氧化硫 45	冷却剂 50	刺激眼和呼吸道, 由于声带或脚水肿可引起死亡 55	

Chart 6-25 (continued from page 255)

5. Carbon dioxide
6. Carbon monoxide
7. Carbon tetrachloride
8. Chlorobromomethane
9. Ethylene alcohol
10. Ethyl liquid
11. Source of poison
12. Anti-freezing liquid, fuel, high pressure liquid component (ethyl alcohol, glycerine)
13. Slide decomposed products or in smoke formed under the effects of high temperature and in high pressure liquid compositions
14. The gas used in motors and heating equipment or other fuels, in paint and in high pressure liquid pumps
15. In fire extinguishers, waste gases or smoke compositions and from dry ice
16. In smoke and waste gases
17. In fire extinguisher compounds
18. In fire extinguisher compounds
19. Cooling liquids and high pressure liquid compositions
20. Fuel additives
21. Toxic effects
22. Inhibition effects, irritation of the eyes and respiratory tract; visual impairment
23. Irritation of eyes and throat; inhibitory effects
24. Inhibition caused by absorption through skin or lungs, anemia, nausea, headaches, deficiency of white blood cells
25. Respiration quickens, suffocation; loss of consciousness when concentration in air reaches 10%
26. Headaches, dizziness, unclear consciousness, sudden loss of consciousness
27. The sustaining of heat forms phosgene and causes headaches, dizziness, shock and eye irritation
28. Inhibition and irritation
29. Slight irritation upon inhaling
30. Insomnia, restlessness, excessive talking, hallucinations and uncoordination in movements
31. Characteristics of existing poisons
32. Odor of alcohol, eye and throat irritation
33. Odor of banana oil, irritation of throat
34. Odor of exhaust gas (gasoline)
35. No odor, suffocation, irritation of eyes and throat
36. No odor, there is waste gas or smoke in the cabin which indirectly indicates its existence
37. Odor of newly cut grass, irritation to eyes and respiratory tract
38. Slight odor of chloroform
39. No odor, yet certain decomposed products have the odor of hot fat
40. Its existence is judged by its gasoline odor
41. Type of compound

42. Biomomethane
43. Chloromethane
44. Nitrogen dichloride
45. Sulphur dioxide
46. Source of poison
47. From compounds of fire extinguisher
48. Coolant
49. From waste gases and fireworks (ammunition)
50. Coolant
51. Toxic effects
52. Inhibitory effects, vision and speech impairment and fuzzy consciousness
53. Headaches, dizziness and nausea, fuzzy consciousness and convulsions
54. Irritation of eyes and respiratory tract
55. Irritation of eyes and respiratory tract, death due to vocal cords of pulmonum oedema
56. Characteristics of existing poisons
57. A weak gratifying odor which forms an irritating gas when it comes in contact with fire
58. Irritation, forms hydrochloric acid when it encounters fire
59. Violently irritating odor, coughing, irritation of eyes and throat

## 2. Permissible Concentration of Toxic Substances

The large majority of permissible concentrations of toxic substances for aircraft and airships are discussed in terms of industrial stipulations and we have still not seen a special standard. This being the case, this book can only cite foreign industrial regulations. Table 6-26 records data on this subject. All of these safety standards are the maximum permissible concentration values of long time exposure. Generally, aviation and space navigation exposure time cannot be as long as industrial exposure. Therefore, it is only able to act as a general reference. For the safety standards of short time exposure see tables 6-26 and 6-27.

1	有毒气体	8	24小时暴露的最大允许浓度(ppm)
2	一氧化碳、氢、甲烷、聚甲醛		10
3	硫化氢、吲哚、粪臭素、氨、甲基硫醇		50
4	有机污染		100
5	无机污染		10
6	重金属		1
7	盐化合物：如氟化氢、氯化氢		3

Table 6-26 The Maximum permissible Concentration of Partially Toxic Gases for 24 hours of Exposure

1. Toxic gases
2. Carbon monoxide, hydrogen, methane, polycresal
3. Hydrogen sulphide, indole, shatole, ammonia, methyl mercaptan
4. Organic pollution
5. Inorganic pollution
6. Heavy metal
7. Salt compounds such as hydrogen fluoride and hydrogen chloride
8. Maximum permissible concentration (ppm) in 24 hours of exposure

1	材料	6	在高温作用下、 的分解产物	1	最大允许浓度 (ppm)	5	材料	2	在高温作用下 的分解产物	3	最大允许浓度 (ppm)
2	武器中包含的物质 四氯化碳				25		液压液体	16	二氧化碳	22	5000
		7	氯化氢		5				一氧化碳	23	40
		8	氯		1		油	17	二氧化碳	24	5000
		9	光气		1				一氧化碳	25	40
3	溴氯甲烷				40				二氧化碳	26	5000
		10	溴化氢		1		橡胶	18	氯	27	0.1~1
		11	溴		1		塑料物质	19	二氧化碳	28	5000
4	甲基溴				20				一氧化碳	29	40
		12	溴化碳		0.50				臭氧	30	0.1
5	机油				40		玻璃液体	20	氯	31	0.1~1
		13	一氧化碳						氯化氢	32	0.05

Table 6-27 The Maximum permissible Concentration of Decomposed Products of Certain Materials Inside the Cabin Under High Temperatures

1. Material
2. Carbon terachloride contained in weapons
3. Bromochloromethane
4. Methyl bromide
5. Engine oil

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6. Decomposed produce under high temperature
7. Hydrogen chloride
8. Chlorine
9. Phosgene
10. Hydrogen bromide
11. Bromine
12. Carbon bromide
13. Carbon monoxide
14. Maximum permissible concentration (ppm)
15. Material
16. Hydraulic liquid
17. Paint
18. Rubber
19. Plastic substance
20. Silicon rectifier
21. Decomposed product under high temperature
22. Carbon dioxide
23. Carbon monoxide
24. Carbon dioxide
25. Carbon monoxide
26. Carbon dioxide
27. Halogen
28. Carbon dioxide
29. Carbon monoxide
30. Ozone
31. Halogen
32. Hydrogen silicide
33. Maximum permissible concentration (ppm)

## Section Six Human Body Pollutions

### 1. General Remarks

The human body is also a source of pollution. The metabolic products of the human body include over 400 types of chemical substances; 149 types are eliminated by respiration, 229 types from the urine, 196 types in the feces, 151 types in the perspiration and 271 types are eliminated on the surface of the skin. Aside from these, there are also the bacterial pollutions of the human body and the gases eliminated from the gastrointestinal tract. Under earth life conditions the pollutions created by the human body easily attain a harmful level. For example, a healthy person eliminates about

50 milliliters of methane per day and after 30-40 days of navigation the methane concentration in a cabin with several people can approach the danger of explosion. Further, if 3 subjects live in a 24 meter<sup>3</sup> airtight cabin, on the eighth or ninth day the carbon monoxide concentration in the cabin reaches 0.016-0.038 milligrams/liter which has already reached the irritation reaction threshold value (0.023-0.027 milligrams/liter) caused by 8 hours of exposure.

When a person lives in an airtight cabin for 24 hours, 298 milligrams of ammonia, 278 milligrams (non-smokers) or 417 milligrams (smokers) of carbon monoxide, 505 milligrams of hydrocarbon, 0.59 milligrams of aldehyde, 232 milligrams of ketone, 4.95 milligrams of mercaptan and hydrogen sulphide and 89 milligrams of fatty acid are eliminated. The concentrations of these substances can reach or exceed the maximum permissible concentration of industrial air. The gas pollutions of a man living in an airtight cabin are shown in tables 6-28 and 6-29. The three charts in chart 6-18 represent the accumulation of carbon monoxide, hydrogen and methyl allyl when there are people and no people in an airtight cabin. Tables 6-28 and 6-29 show the toxic compositions eliminated by humans inside an airtight cabin.

1 物 质	10 舱内实测含量 (毫克/升)	13 最大可允许浓度 (毫克/升)
氨及其化合物	0.026	0.02
醛	11 痕 迹	—
酮	0.023	0.2
硫化氢和硫醇	12 痕 迹	—
有机酸(由醋酸算出)	0.012	0.005
不抽烟人的一氧化碳	0.012	0.02
抽烟人的一氧化碳	0.018	0.02
烃总数(由碳算出)	0.026	0.3

Table 6-28 The Toxic Substance Pollutions After 1 Person Remains in a 5 Meter<sup>3</sup> Airtight Cabin for 5 hours

1. Substance
2. Ammonia and its chemical compounds
3. Aldehyde
4. Ketone
5. Hydrogen sulphide and mercaptan
6. Organic acid (calculated by acetic acid)
7. Carbon monoxide of a non-smoker
8. Carbon monoxide of a smoker
9. Hydrocarbon total (calculated by carbon)
10. Measured content in cabin
11. A trace
12. A trace
13. Maximum permissible concentration (milligrams/liter)

1 气 体	9 实测的最大值	10 正 常 值	11 警 戒 值
2 一氧化碳(ppm)	29.0	19	100
3 二氧化碳(%)	2.3	1	3
4 烃(ppm)	20	5	400
5 NH <sub>3</sub> (ppm)	7	0.5	100
5 醛(ppm)	1.05	0.2	20
SO <sub>2</sub> (ppm)	0.2	0.05	0.8
H <sub>2</sub> S(ppm)	0	0	16
(NO) <sub>x</sub> (ppm)	0	0	0.8(在50%氧, 50%氧下) 12
O <sub>3</sub> (ppm)	0	0	0.016
6 氯(ppm)	0.003	0	0.16
7 氟化物(ppm)	0	0	1.6
8 氟化碳基质(ppm)	0	0	0.16

Table 6-29 Gas Pollution of 4 Persons Living for 30 Days in a 108 Meter<sup>3</sup> Cabin

1. Gas
2. Carbon monoxide (ppm)
3. Carbon dioxide (%)

4. Hydrocarbon (ppm)
5. Aldehyde
6. Chlorine (ppm)
7. Cyanide (ppm)
8. Carbon chloride (ppm)
9. Measured maximum value
10. Normal value
11. Warning value
12. 0.8 (in 50% nitrogen and 50% oxygen)

## 2. Exhaled Gases

Human exhaled gases include gases exhaled from the lungs and respiratory tract, gases and substances exhaled from the esophagus, saliva and oral cavity and there are more than 100 types of compositions. The amount of carbon dioxide in the exhaled gases is 0.011-0.003 milligrams/liter, the carbon monoxide does not exceed 0.5-1.05  $\text{cm}^3$  /hours and the average is 10 cubic centimeters per day. The concentration of ammonia in a healthy person's exhaled gases is very low; its total quantity is 0.02-0.4 grams per day, there is also acetone in the exhaled gases and 0.03-0.08 grams of this acetone is exhaled each day. The various compositions and concentrations of exhaled gases are listed in table 6-30. There are variations for different foods, work, temperatures and noises, as shown in table 6-31 and chart 6-18.

1 排 出 物	11 休 息 时		14 劳动时(能量消耗200千卡/小时)		17 劳动时(能量消耗400千卡/小时)
	12 用指定的食谱	13 自由进食	15 用指定的食谱	16 自由进食	18 用指定的食谱
2 二氧化碳	27700 ± 1600	24500 ± 2800	57700 ± 4000	71400 ± 9500	156500 ± 8200
3 氧	5.3 ± 1	4 ± 1.5	13 ± 3	15 ± 3	27 ± 6
4 烃	21 ± 3	60 ± 8	40 ± 5	165 ± 21	88 ± 19
5 丙酮	0.4 ± 0.1	0.5 ± 0.2	1.9 ± 0.5	9.8 ± 2.1	11 ± 3
6 苯	0.5 ± 0.2	0.2 ± 0.17	6.4 ± 1.4	24 ± 14	17 ± 3
7 氨	0.7 ± 0.1	0.4 ± 0.15	26 ± 6.4	39 ± 10	21 ± 7
8 胺	1 ± 0.4	0.55 ± 0.1	12.2 ± 3.9	39 ± 10	135 ± 40
9 氯化物	43 ± 14	77 ± 18	415 ± 94	590 ± 75	690 ± 40
10 醛	0.02 ± 0.01	0	0.1 ± 0.05	0.05 ± 0.02	0.1 ± 0.01

Table 6-30 The Speed (Milligrams/Hour) of Toxic Substance Elimination When a Person is Resting and Working (the average number-standard error)

1. Substance eliminated
2. Carbon dioxide
3. Oxygen
4. Hydrocarbon
5. Acetone
6. Benzene
7. Ammonia
8. Amine
9. Chloride
10. Aldehyde
11. Rest time
12. Using a fixed menu
13. Free intake of food
14. Work time (energy consumption is 200 kilocalories/hour)
15. Using a fixed menu
16. Free intake of food
17. Work time (energy consumption is 400 kilocalories/hour)
18. Using a fixed menu

1 平均温度(℃)	2 环 境 条 件		有毒气体排出量	氢化物排出量	有 机 物
	3 其 他 条 件		12 (公斤)	13 (克)	14 (克氧)
10.1	正 常	4	1.34	0.083	0.084
2.2	正 常	5	1.27	0.094	0.134
31.4	正 常	6	2.18	0.281	0.257
43.8	正 常	7	7.6	0.441	0.804
44.6	正 常	8	8.41	0.248	0.686
44.1	噪声105~110分贝	9	9.52	0.344	0.686
44.3	γ射线剂量率4.2微伦/天	10	9.42	0.354	0.761
43.8	噪声105~110分贝, γ射线4.2微伦/天	11	7.6	0.441	0.804

Table 6-31 Foreign Substances in Exhaled Gases Per Person  
Per Day Under Different Environmental Conditions

1. Average temperature (°C)
2. Environmental conditions
3. Other conditions
4. Normal
5. Normal
6. Normal
7. Normal
8. Normal
9. Noise is 105-110 decibels
10. Gamma ray dosage rate is 4.2 microroentgen/day
11. Noise is 105-110 decibels and gamma rays are 4.2 microroentgen/day
12. Quantity of toxic gases eliminated (kilograms)
13. Quantity of amino compound (grams)
14. Organic substance (grams of oxygen)

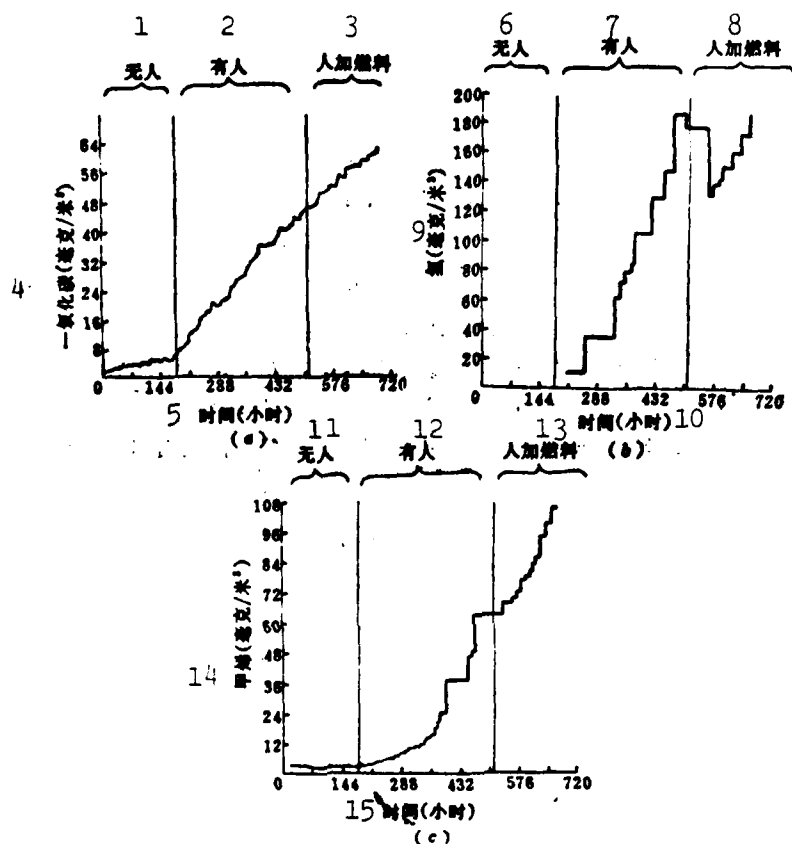


Chart 6-18 The Ascending Process of Gas Composition Concentrations in an Airtight Cabin (the gas pressure in the cabin is 258 millimeters on the mercury column and the temperature is 21.1°C)

- (a) Concentration of carbon monoxide
- (b) Hydrogen concentration
- (c) Methyl allyl concentration
- 1. No people
- 2. With people
- 3. People and fuel
- 4. Carbon monoxide (milligrams/meter<sup>3</sup>)
- 5. Time (hours)
- 6. No people
- 7. With people
- 8. People and fuel
- 9. Hydrogen (milligrams/meter<sup>3</sup>)
- 10. Time (hours)
- 11. No people
- 12. With people
- 13. People and fuel
- 14. Carbon monoxide (milligrams/meter<sup>3</sup>)
- 15. Time (hours)

12. With People
13. People and fuel
14. Methyl allyl (milligrams/meter<sup>3</sup>)
15. Time (hours)

### 3. Skin Excrement

The surface of human skin continually excretes substances including perspiration and substances excreted from the sebaceous glands and in cutaneous respiration. For the main ingredients of perspiration see table 6-32. Each week the sebaceous glands excrete about 100 grams and sometimes as much as 200-300 grams. The main ingredients of a healthy person's sebaceous glands are: 30% free fatty acid, 38% volatile fatty acid and other substances that cannot be saponified such as protein, inorganic acids, glycerine, palmitin, salt and other substances. Respiration is also carried out on the surface of the skin and within this respiration process there are also pollution gases eliminated.

1 物 质	10 含 量	12 物 质	21 含 量	22 物 质	30 含 量
水(%)	2 99.2~99.7	氮(毫克%)	13 23~40	尿素氮(毫克%)	23 12~39
固体物质(%)	3 0.3~0.8	氯化钠(莫尔当量/升)	14 5~148	氮(毫克%)	24 5~9
有机固体物质	4 0.03~0.3	钾(莫尔当量/升)	15 1~15	肌酸(毫克%)	25 0.1~1.3
灰	5 0.14~0.57	钙(莫尔当量/升)	16 1~8	尿酸(毫克%)	26 0~15
铁	6 0.1~0.2	磷(毫克%)	17 0.4	氨基酸氮	27 痕迹 31
碘、氯、溴	7 痕 迹	铜(毫克%)	18 0.4~7.5	脂	28 痕迹 32
乳酸(莫尔当量/升)	8 4~40	锰(毫克%)	19 3~7	组织氮	29 痕迹 33
葡萄糖(莫尔当量/升)	9 0.1~9	硫酸盐(毫克%)	20 4~17		

Table 6-32 Substance Content in Human Respiration

1. Substance
2. Water (%)
3. Solid substances (%)
4. Organic solid substances

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5. Ash
6. Iron
7. Iodine, fluorine, bromine
8. Lactic acid (Mohr equivalent)
9. Glucose (Mohr equivalent)
10. Contents
11. Traces
12. Substance
13. Nitrogen (milligrams %)
14. Sodium chloride (Mohr equivalent)
15. Potassium (Mohr equivalent)
16. Calcium (Mohr equivalent)
17. Magnesium (milligrams %)
18. Copper (milligrams %)
19. Manganese (milligrams %)
20. Sulphate (milligrams %)
21. Contents
22. Substance
23. Urea nitrogen (milligrams %)
24. Ammonia (milligrams %)
25. Creatine (milligrams %)
26. Uric acid (milligrams %)
27. Nitrogen amino acid
28. Phenol
29. Histamine
30. Contents
31. Traces
32. Traces
33. Traces

#### 4. Intestinal Tract Gases

The gases formed in the intestinal tract by one person each day is about 800-1,000 milliliters, the average is 1.47 milliliters/minute and about 50-200 milliliters are eliminated each time with an average of 100 milliliters. The gases formed in the gastrointestinal tract are mainly decomposed by chemical compounds in the intestines which results in gas discharge (mainly nitrogen) and bacterial activity. Air can also be swallowed into the stomach by swallowing. The air in the stomach is generally only 50 milliliters and the majority is either belched out or enters the intestines. The air composition in the

stomach is basically equal to the outside air. However, there is relatively more carbon dioxide (occupying 5-9%). Within this, part of the oxygen is absorbed by the tissues and the larger part of the remaining is nitrogen which enters the intestinal tract. The upper and middle part of the small intestines usually do not have gas and the large intestines usually have about 100 milliliters of gas. The gas compositions of the gastrointestinal tract differ according to the quality of the food and bacterial activity. For example, after eating legumes and raw cucumbers, the gases in the intestines increase 10-20 times. In order to avoid abdominal distension astronauts and high altitude pilots must eat less legumes, bean products and raw cucumbers. See table 6-33 for the main compositions of intestinal gases under normal conditions. The table also shows that when the accumulation of these gases reaches a certain level there are physiological effects.

1 物 质	2	9 大肠气体含量 (分子%)	10 舱内最大允许浓度		标准舱内积累到最大允许浓度的天数	13 超过最大允许浓度时的生理影响	
			ppm	11毫克/升			
硫化氢	2	$0 \sim 0.6 \times 10^{-4}$	20	0.029	148	麻醉、恶心	14
氢	3	$0 \sim 5.4$	—	—	44	爆炸(爆炸浓度4.1%)	15
甲烷	4	$0 \sim 55$	—	—	59	爆炸(爆炸浓度5.3%)	16
二氧化碳	5	$4 \sim 6$	5000●	$9.0 (\sim 0.5\%)$	10	肺换气量稍见增大	17
二氧化氮	6	$4 \sim 6$	30000●	$54 (\sim 3\%)$	60	呼吸困难	18
氮	7	$10 \sim 88$	—	—	—	—	—
氧	8	$0 \sim 10$	—	—	—	—	—

19 ● 采取二种不同的安全标准,故最大允许浓度有二个数值,生理影响也有二种不同情况。

Table 6-33 The Contents of the Main Pollutants, the Maximum Permissible Concentration in the Cabin and the the Physiological Reactions of the Gases in the Large Intestines

1. Substance
2. Hydrogen sulphide

3. Hydrogen
4. Methyl allyl
5. Carbon dioxide
6. Carbon dioxide
7. Nitrogen
8. Oxygen
9. Contents of gas in large intestines (molecules %)
10. Maximum permissible concentration in cabin
11. Milligrams/liter
12. The standard number of days of accumulation in the cabin reaching the maximum permissible concentration
13. Physiological effects when exceeding the maximum permissible concentration
14. Eye irritation, nausea
15. Explosion (explosion concentration is 4.1%)
16. Explosion (explosion concentration is 5.3%)
17. Slight increase in pulmonary breathing
18. Respiration difficulties
19. Two different types of safety standards were used and therefore there are two values for the maximum permissible concentration and two different types of situations for the physiological effects

## 5. Urine and Feces

### 1. Urine

Each day a healthy person eliminates 1,000-1,600 milliliters of urine which is 95% moisture and 5% organic and inorganic substances. There are 229 types of chemical compounds in urine including 103 types of nitrides, 30 types of electrolytes, 38 types of endocrines, 10 types of enzymes as well as vitamin fatty hydrocarbons and organic acids. See table 6-33 for the main compositions of urine. A certain period after urine is eliminated, the volatilized gas pollution undergoes certain changes due to the joint action of bacteria and preservatives with the container substances. Table 6-34 lists these changes.

1 物	质	11 保存 3 昼夜的尿	12 保存 5 昼夜的尿	13 保存 10 昼夜的尿
氨和 $\alpha$ -胺	2 3 4 5 6 7 8 9 10	0.014	0.019	0.061
酮		0.0006	0.008	0.001
有机酸 (按醋酸算出)		0.028	0.076	0.0139
烃 (按碳算出)		0.094	0.079	0.173
酚		0.006	0.007	0.0019
硝酸 (按 $N_2O_5$ 算出)		0.0013	0.001	0.015
硫化氢和硫醇		—	—	—
硫化气体		—	—	—
一氧化碳		0.035	0.012	0.018

Table 6-34 The Gas Composition of Excreted Human Urine Preserved for 3-10 Days (milligrams/10 milliliters)

1. Substance
2. Ammonia and  $\alpha$ -amine
3. Ketone
4. Organic acids (calculated by the acetic acid)
5. Hydrocarbons (calculated by the carbon)
6. Phenol
7. Nitric acid (calculated by the  $N_2O_5$ )
8. Hydrogen sulphide and mercaptan
9. Sulphur gas
10. Carbon monoxide
11. Urine preserved for 3 days and nights
12. Urine preserved for 5 days and nights
13. Urine preserved for 10 days and nights

## 2. Feces

Human elimination of feces depends on food, the digestive functions, the special characteristics of metabolism and living habits. The average quantity eliminated per day is 250-300 grams. Feces contains 75% water and 25-30% other substances (calculated by weight) which includes bacteria, undigested substances and other substances. Feces contain a large amount of protein and fatty metabolized substances (nearly 2 grams/day) including amino acid, fats, neutral fats and free fatty acids. It also contains bile (feces bile pigment), other decomposed

substances (nearly 0.5 grams/day) and certain minerals such as potassium, phosphorous, magnesium, iron, phosphate, aluminum, nickel, copper, mercury, sulphur, zinc and sodium. Human feces contains 0.02-0.16% ammonia and 0.36-1.2 milligrams/kilogram body weight of ammonia nitric acid. The main gas pollutions of human feces are listed in table 6-35.

1 有 毒 物 质	13 新 鲜 的 粪 (毫克/100毫克粪)	16 保 存~5 天 的 粪 (毫克/100毫克粪)	17 最 大 允 许 浓 度 (毫克/米 <sup>3</sup> 粪)	
氨和α-胺	2	0.019	1.35	20
硫醇和硫化氢	3	痕迹~0.113 <sup>14</sup>	0~0.04	3
酚	4	0.009	0.08	5
吲哚和粪臭素(同甲基氨基)	5	痕迹~0.013 <sup>15</sup>	0.005~0.009	—
有机酸(由醋酸算出)	6	0.26	0.86	5
硝酸(按N <sub>2</sub> O <sub>5</sub> 算出)	7	0.06	0.28	5
烃(由CH <sub>4</sub> 算出)	8	0.8	0.9	300
、 一氧化碳	9	0.12	0.02	20
醛	10	—	最大为痕迹	—
酮	11	—	0.16	—
硫气体	12	—	0.01	—

13 注: 人粪100克放入8升容积的密闭玻璃瓶内, 瓶内气体用吸收剂吸收, 并换入新鲜净化空气, 共2小时, 测定由粪进入空气内的污染物质, 表内数值均为污染物质浓度。

Table 6-35 Gas Pollution and Their Changes in Human Feces

1. Toxic substance
2. Ammonia and α-amine
3. Mercaptan and hydrogen sulphide
4. Phenol
5. Indole and skatole
6. Organic acids (calculated by the acetic acid)
7. Nitric acid (calculated by the N<sub>2</sub>O<sub>5</sub>)
8. Hydrocarbons (calculated by the CH<sub>4</sub>)
9. Carbon monoxide
10. Aldehyde
11. Ketone
12. Sulphur gas
13. Fresh feces (milligrams/100 milligrams of feces)
14. Traces - 0.113
15. Traces - 0.013

16. Feces preserved for 5 days (milligrams/100 milligrams of feces)
17. Maximum permissible concentration (milligrams/meter<sup>3</sup> cabin)
18. Note: 100 grams of human feces is placed in an 8 liter airtight glass bottle, the gases in the bottle are absorbed by an absorbent and exchanged for fresh purified air. In 2 hours, it is determined by the pollution substances in the feces that entered the air. The numerical values in the table are all the concentrations of the pollution substances

#### 6. Bacterial Pollution

There are about  $10^{14}$  intestinal bacteria in the human body. Most intestinal bacteria are not only harmless but they also form a closed ecosystem with the human body which is a symbiotic system. These bacteria are mainly transmitted from the outside yet only a minority self-reproduce and transmit. If they are not continually transmitted in through the food the bacteria in the intestines become less and finally there is only one type of master bacteria and saccharomycete remaining. This conclusion is the results attained after long term intake of food without bacteria. However, this does not explain that the bacteria cannot emerge and perish of itself in the intestinal tract because the reproduction and death of one type of bacteria is related to other bacteria.

After people live in an airtight cabin for a long time, the number of skin and mucous membrane bacteria nearly double. This signifies that humans are a very important source of bacterial pollution and it also indicates that before an air-ship cabin has reached a level of perfection for control of

bacterial pollution we must await further research and attempts at controlling this pollution by medical personnel.

7. The Physiological Effects Threshold Value of Human Body Pollution Substances

The minimum concentration of several types of major human body pollution substances which cause physiological effects is called the physiological effects threshold value. Table 6-36 lists the safety limits for some of these types of harmful substances.

See next page for Table 6-36

2 物 质	11 嗅 觉 阈 (毫克/米 <sup>3</sup> )	13 生 理 反 应 阈 (毫克/米 <sup>3</sup> )	14 生 理 反 应 种 类	
氨	—	20	皮电反应	15
	—	40~50	脑电图	16
	0.5	0.45	视觉光感受性	17
	0.5	0.35	脑电图	18
酮	1.1	0.55	视觉光感受性	19
	—	0.44	耳蜗电反应	20
	1.096	—	—	—
	1.1	—	—	—
间 胺	—	0.12	皮电反应	21
	4.3	3.3	视觉光感受性	22
	4.5	3.15	视觉光感受性	23
	—	1.17	脑电图	24
酚	3.5~4.0	—	—	—
	0.022	0.0155	视觉光感受性	25
	—	0.0156	耳蜗电反应	26
	0.022	—	—	—
硫 化 氢	0.04	—	—	—
	0.014	—	—	—
	0.1	—	—	—
肝	1.6~2	0.6	视觉光感受性	27
	—	0.6	耳蜗电反应	28
一氧化碳气体	—	0.5(%)	脑电图	29
粪 臭 素	1~2次大便不通宜贮存 12	—	—	—
醋 酸	5.0	1.0	皮电反应, 脑电图α节律抑制	30

Table 6-36 The Physiological Effects Threshold Value of Certain Products on Human Body Life Activity

1. Substance
2. Ammonia
3. Ketone
4. Meta-amine
5. Phenol
6. Hydrogen sulphide
7. Anhydride
8. Carbon monoxide gas
9. Slatole
10. Acetic acid
11. Smell threshold (milligrams/meter<sup>3</sup>)



12. 1-2 times of defecation are not suitable to storage
13. Physiological effects threshold (milligrams/meter<sup>3</sup>)
14. Type of physiological reaction
15. Skin electricity reaction
16. Electroencephalogram
17. Visual light sensitivity
18. Electroencephalogram
19. Visual light sensitivity
20. Cochlea electricity reaction
21. Skin electricity reaction
22. Visual light sensitivity
23. Visual light sensitivity
24. Electroencephalogram
25. Visual light sensitivity
26. Cochlea electricity reaction
27. Visual light sensitivity
28. Cochlea electricity reaction
29. Electroencephalogram
30. Skin electricity reaction, electroencephalogram alpha rhythm inhibition

## CHAPTER TWENTY-FOUR

### AVIATION MEDICAL GUARANTEES

#### Section One    Characteristics of Various Aircraft Work

It was already stated in Chapter One that the main content of aerospace medical science is the study of the effects of the various special environmental conditions in aviation and space navigation on the human body and the methods of protection against them. This chapter as well as the next separately discuss what medical requirements are needed for pilots and astronauts and how to guarantee their safety, work capabilities and physical health in space. Below we will first introduce the various characteristics of flight work.

Flight work is a relatively special type of work and the special features of work in various types of flight are not the same. There are many factors which constitute the special features of flight work and among them the most important are: flight tasks; flight environmental (meteorological phenomena, region etc); aircraft type (related to flight altitude, speed and cabin type); flight course (cruising, stunt flying).

#### 1. Flight Tasks

Since flight tasks are different there are great discrepancies in flight requirements. For example, civil aviation includes transport flights, specialized flights and also training

flights. Transport planes include scheduled domestic and international flights transporting passengers, goods and mail as well as special and chartered plane tasks. Generally speaking, these types of flights possess many special requirements for safety, comfort and flight normalcy. Modern high altitude, high speed large jet passenger planes can seat several hundred people and the guarantee of flight safety is the primary task of the air crew and is an even greater responsibility for leading flight personnel on special planes and chartered planes. In flights where energy is concentrated, there is mental tenseness and for long distance and long time flight fatigue is easily produced. The life, as well as eating, work, and rest system of the air crew must change in accordance with the changes of scheduled flight time and produced tasks. Because of this, there is often irregular lifestyle in flight and empty or full stomach flights are common; when making international flights the time difference changes are greater and moreover this not only changes the night and day rhythm but there are also seasonal shifts. Under these conditions people often do not eat or sleep well. In special flights non-airtight medium and small scale transporters and helicopters are used for seeding, spreading fertilizer, spreading agricultural chemicals, forest fire prevention, scouting for schools of fish, emergency disaster relief, aerial photography and aerial prospecting. The main features of these types of flights are complex tasks, sometimes there are low and extremely low altitude (5-10 meters) flights,

work fluidity is great, field operation conditions are relatively lacking and sometimes one cannot but be affected by chemical drugs.

Military transporters and bombers have many points of similarity with civil aviation planes yet they have more problems in load, fighting task, and mobile flight than civil aviation planes but less than fighters. Aside from pilots, there are also navigators, radio operators, mechanics and shooting personnel on these types of aircraft. Furthermore, these types of aircraft often fly under poor weather conditions and because of this the flight personnel (especially the pilot) on these types of aircraft must have appropriate flight ability for flying under complex weather conditions.

Fighter planes have great mobility, many stunt courses, great acceleration and in stunt flight Coriolis acceleration is produced. Aside from these, in complex weather conditions, night flights and fighting there is the possibility of being wounded, parachuting and escaping from danger. Based on these factors, the requirements for fighter plane pilots are even stricter.

## 2. Flight Environment

Flight environment mainly points to the two fields of weather and region. The technical demands for pilots under most weather conditions during day flights are not very high. During the flights there is visual flying but during the night flights one must depend on the instruments. The technical

demands of instrument flights are relatively high and moreover this demands that the pilots have relatively good night vision. Night flights under complex weather conditions also require that the pilot have a certain ability to adapt to bumping, vibration flight illusions and motion sickness. Regionally, ocean flights, desert flights and mountain flights are much more difficult than continental flights. During ocean flights the horizon is not easily discriminated and there are the effects of mirages. At night, it is difficult to discriminate the ocean and sky and thus flight illusions easily occur. In desert flights, the differences between the ground and aerial temperatures are great and the air's violent convection can cause aircraft bumping. During flights over high mountain areas, the thin dry air and low air temperatures easily cause mountain non-adaptation and upper respiratory tract infection; furthermore, high mountain air changes are sudden and the air flow disturbances are fierce which cause fatigue and airsickness. After the flight, fatigue is slowly eliminated. When flying under scorching temperature conditions astronauts generally lose their appetites, do not sleep enough and easily become sick; further, because of the scorching temperature conditions the temperature in the cabin increases causing the regulation load of human body temperature to become heavier which causes flight ability to decrease. When flying in very cold weather, flight personnel easily get frostbite and respiratory tract infection; snow blindness easily occurs when flying over a

polar region the danger of cosmic rays is much greater than over the region of the equator. Thus, at this time, one must consider protection against radiation.

### 3. Types of Aircraft

The flight conditions for different types of aircraft are different and each has its special features. For example, a jet, a propeller aircraft and a helicopter have differences in pollution. Furthermore, a helicopter's propeller forms flashing lights in the cabin (shadows of the rotary wing) which often causes illusions and blurred vision. The differences in flight labor on different types of aircraft are mainly in flight altitude, speed and conditions in the cabin. For example, when an aircraft is flying at an altitude of 2-3 kilometers it generally does not require a supply of oxygen; oxygen supply is required at 4 kilometers; above 10,000 meters an airtight cabin is required; for flights above 20,000 meters it is necessary to consider the effects of cosmic radiation and ozone. The problems of trembling at low altitude high speed flights and reaction flexibility of vision during high speed flights cannot be overlooked. The effects of cabin conditions on flight work are also very great and in cabins that are not airtight the ventilation inside and outside the cabin, and the temperature and moisture inside the cabin all change in accordance with the altitude. Moreover, the effects of noise, vibration, bumping and harmful gases are great. Thus, the number of people who suffer from airsickness is greater in cabins that are not

airtight. The temperature and moisture in an airtight cabin can be regulated automatically and its environmental conditions are better.

#### 4. Flight Course

The different flight courses and flight stages have a very large affect on flight work. For example, the control activities for takeoff and landing are generally more complex and intense than when cruising. During landing a pilot must perform over 300 movements within 5 minutes. Moreover, the discrimination demands for altitude, speed and flight conditions are relatively high and the feelings of acceleration, impact, pressurization and decompression are also more noticeable. Aside from these, during instrument flights passing through clouds often creates flight illusions; when turning the effect of revolving is often produced; during reconnaissance, photographing, interception, attack and mobile flight there are special demands on flight technology; yet, when stunt flying these types of demands are even higher. All of these flight courses require certain aerial vision abilities, visual searching abilities and observation abilities.

#### Section Two    The Medical Selection of Student Pilots

The medical selection of student pilots is an important responsibility of the health department. They must select students with qualified physiques and flying fitness to study flying so that they can undertake the task of takeoff after the training period. Selection should decrease the elimination

rate of students and raise the quality and fighting ability of the pilots. Thus, it goes without saying that selection is very significant. Beginning from this point, it can be said that selection is a key link in guaranteeing aviation medicine.

The medical selection of student pilots can be divided into two types: one stage selection and multiple stage selection. It can also be divided into two major categories: the medical selection in the narrow sense which takes the physical examination as the basis and the so-called physio-psychological selection which takes the characteristics of perception and nervous system reactions as the basis.

So-called one stage selection is the direct selection into aviation school for training from among suitably aged youths. This method can save manpower, material resources and time, yet, because of the limitations of the method and later physical body changes, the rate of error in one time selection is relatively high. Therefore, in peace time it is rarely used. So-called multistage selection is the optimum seeking method with gradual investigation and repeated screening to complete the method of selecting qualified students to study flying. Whether it is one stage or many, both necessitate medical examinations and physio-psychological selection but unfortunately there is still no uniform perfect internationally standard. Therefore, the development and improvement of selection examination methods and the raising of the selection coincidence rate are key links for guaranteeing the quality of selection.



Medical selection which takes the physical health examination as the basis uses the examination methods of each department in a medical clinic and completes the selection of a student pilot's physical condition based on certain standards. Its aim is to require that the selected students possess the physical conditions needed by a pilot. Medical selection standards differ in accordance with task requirements such as aircraft type, fighting requirements etc. At the same time, it is also based on the time of actual flight experience including observations of flight capabilities, surveying flight mishaps and research and discussion of experience and training derived from among the student pilots that were eliminated. In other words, it should not be unalterable but should accord with the advancement of flight technology, the demands of medical practice as well as the continually revised and renewed progress of modern medical science. Moreover, there are different physical selection standards for each type of pilot. The careful introduction of selection standards is the responsibility of aviation clinical medicine. This book will not go into detail on this subject.

The physio-psychological selection which takes perception and nervous system reaction characteristics as the basis is also in principle a component part of medical selection. Yet, because it utilizes an observation method of a general physical examination of many perceptions and nerve reactions which are not used or not often used, it is generally listed

in the physio-psychological test category. Although this be the case, it should not be viewed independent of the medical examination. Because this section of the examination is relatively new we will give a brief introduction to it below.

Physio-psychological selection has gradually been recognized and promoted in the historical development of medical selection. During the initial period of flight development, flight technology was relatively simple and the significance of physio-psychological selection was not fully exposed. During World War One, people began to feel that the simple physical and health examination was unable to fulfil the demands for selecting student pilots, but at the time the physio-psychological selection system had not yet been formulated. During World War Two, the rapid development of flight task frequency and flight technology and the drastic rise in the elimination rate of student pilots seriously affected the replenishing of pilots and directly obstructed the development of air force fighting capabilities. Under these conditions, many nations organized a considerable amount of manpower and material resources to develop physio-psychological selection. A fundamental basis was also formulated at this time for physio-psychological selection. Although it was still in an initial stage at that time yet it had a noticeable effect in decreasing the elimination rate of student pilots. Therefore, physio-psychological selection has gradually been recognized as a necessary component in selecting student pilots. From that time on, physio-psychological selection was not only applied in

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practice but it also became an important research topic in aviation medicine. It has been continually improved, raised and renewed. Yet, the obtained results are still very far from the requirements. For example, according to recent foreign reports, the coincidence of physio-psychological selection only fluctuates in the area of 0.4-0.6 and the problem of how to further raise it is still being researched by many nations.

Theoretically, flying is a type of special profession which requires much more stringent perceptual ability, memory, attention, calculating ability, reaction flexibility and motor coordination than most work. In selecting student pilots it is necessary to consider these related qualities. This is the theoretical basis required for physio-psychological selection; the more precise these are shown to be the higher the coincidence of selection.

Below is a brief summary of the general principles implemented for flight student medicine (including medical physical examination and physio-psychological examinations).

- 1) The examiner must be serious and conscientious in control accuracy, testing instruments and equipment and the environmental conditions must coincide with the scientific requirements. When testing at different times, places and different subjects there must be a unified standard.

- 2) The examinee must be serious, conscientious, cooperative and prevent the effects of negative factors such as fatigue, tension, insomnia and hunger.

3) The recording of examination results must be close, thoughtful and complete.

4) The analysis and arrangement of examination results must be scientific. When using comprehensive calculations one should utilize appropriate mathematical statistics so that the comprehensive calculations will be able to accurately reflect objective characteristics.

### Section Three Medical Problems in Flight Training

Flight training is basically composed of three fields:

#### 1. Training in Flight Theory and Knowledge

This includes flight technology, maintenance knowledge, physical meteorological and other technical and scientific knowledge related to aviation, and common knowledge of aeronautical medical science.

#### 2. Simulated Flight Training

This includes glide technical training and various types of ground practice equipment training. In this training a student must study instrument reading, flight control, the use of flight equipment (including the flight suit), emergency escape, ejection, parachuting, rescue techniques as well as adaptation to vibration.

#### 3. Flight Training

In this training the problems of how to implement medical principles and raise training effects have special significance in guaranteeing aviation medical work. The implementation of

medical principles in flight training did not receive the attention it should have in the initial period of aircraft development so that afterwards the more complex the aircraft control technology requirements and the more striking the man-aircraft relations, the more important this problem became. In recent years, following the development of high altitude and high speed aircraft, pilots are not only required to have excellent operating abilities but must also have the ability and endurance to withstand the various special conditions that occur during high altitude, high speed flight. Thus, the implementation of medical principles in flight training has not only gained people's attention but has become absolutely necessary.

Piloting an aircraft is not only an operating process but is also a process which struggles with the various special aircraft conditions. It is also a process which brings the human body's strain capabilities into full play so that in the instant of fighting this point is even more outstanding. Therefore, flight training cannot be simply viewed as a type of complex operations technique training but it should be integrated with the pilot's subjective activity, cultivation of a political sense of responsibility, endurance to special harmful factors in the environment and strain capabilities. The medical principles should play an important role in these areas. These have already been discussed in previous chapters and sections. Here it is necessary to stress them again:

1) During flight training it is necessary to fully consider how to raise the human body's ability to withstand the various special flight conditions. Using the equipment as an example, in the past revolving endurance training was considered. Endurance training for overweightness, anoxia, pressurized oxygen supply, high temperatures and low temperatures were adopted by many nations under different circumstances. Some of these types of training were carried out in special ground equipment such as in a centrifuge, a low pressure cabin or a temperature cabin. Yet, they could also be carried out together with aerial training. In implementing the various training processes mentioned above an aviation physician must formulate a rational balance between work and rest as well as between nutritional health and safety measures.

2) Implement medical principles so as to raise the effects and quality of flight technique training. For example, use medical principles to direct the design of effective ground training equipment including clothing equipment operation techniques, instrument reading, aerial direction, simulated operations, target searching, aiming and firing, night vision training, balance judgement, and training to overcome airsickness and flight illusions. Aside from these, when designing aerial training items, medical principles should be implemented to raise the effect and quality of training.

#### Section Four     Medical Sanitation Safeguards for Pilots

Flight activities are a complex and tense type of work and many harmful special conditions can be encountered in space. Thus, an aviation physician not only must undertake to guarantee that pilots have healthy physiques so as to engage in complex and tense flight work but also should allow the pilots to develop excellent abilities so as to withstand the negative factors in flight. What is especially unable to be neglected is: an aviation physician must at all times pay attention to whether or not the various flight conditions can have negative effects on a pilot's work and health and at all times use effective preventative measures. Specifically, the contents of a pilot's sanitation guarantees should include the following:

- 1) Based on the actual requirements of body power and energy consumption for flight work, guarantee the necessary nutrition, rest and sanitary conditions, have physical examinations at fixed times and inquire into the examination.

- 2) Based on the actual needs of flight work, adopt effective physical training including endurance training to guarantee that the pilot has a healthy physique and good endurance.

- 3) Carry out health protection for the pilot by promptly discovering latent illnesses and declines in flight capabilities, and promptly adopt effective preventative measures.

- 4) Adopt effective protective measures and prevent the organism from producing pathological processes for the negative factors of flight. An aviation physician must often examine the the implementation of these protective measures, examine the

safety and reliability of the protection equipment (such as the air supply, cabin airtightness, environmental maintenance, ejection, rescue parachute high altitude clothing etc.). As soon as a flaw or problem is discovered ideas should promptly be brought forth for improvements so as to raise its effectiveness.

5) When a flight mishap or air incapacity occurs, then a detailed medical examination should be carried out and the reasons should be ascertained so that a lesson can be learned from the experience and accidents can be prevented from happening in the future.

6) In aircraft engineering technical design, the aviation medical personnel aid the engineers in implementing human body engineering principles so that an aircraft system appropriate for humans is used. In this way, man's operational usefulness can be brought into full play and the effects of flight negative factors can be decreased.

Medical sanitation safeguards for pilots not only require aviation medical personnel to have a high political sense of responsibility and conscientiously implement the safeguard but they must also often carry out intellectual propaganda of aviation medicine and aviation medical sanitation safeguards to the pilots, flying instructors, ground crew, maintenance personnel and engineering technology personnel. They must also arouse related personnel to coordinate, mutually supervise and urge, and implement the safeguards together. Only in this way can aviation medical sanitation safeguard work have the broad basis of the masses and fully and effectively develop the functions that they should have. Naturally, the serious attention



and support of the administrative leadership is also very important.

## CHAPTER TWENTY-FIVE

### SPACE NAVIGATION MEDICAL GUARANTEES AND MEDICAL SUPERVISION

#### Section One Preface

When compared to aviation, space navigation medical guarantees and medical supervision have their own particularities. For example, space navigation is generally few in number and long in time and the number of people during each time of navigation is relatively few. Most astronauts are selected from among pilots. There are many differences between the special conditions and environmental factors that they endure in space navigation and those they encounter in an aircraft. Besides these, there are also great differences between an airship's structure, performance, equipment, instruments, individual protective devices, emergency escape, safety measures, operations techniques and maintenance with that of an aircraft. Based on the above mentioned circumstances and reasons, although space navigation medical guarantees and medical supervision requires drawing experience from aviation medical guarantees yet is necessary for space navigation to set up its own independent system so as to satisfy the actual conditions and needs of space navigation.

Briefly, space navigation medical guarantees and medical supervision should include the following five fields:

- 1) Medical selection of astronauts
- 2) Medical guarantees and supervision of astronauts during training
- 3) Medical guarantees and supervision prior to navigation
- 4) Medical guarantees and supervision during navigation
- 5) Medical observations and supervision after navigation

Later we will briefly discuss these fields in separate sections.

Before beginning to discuss the contents of these fields we must use a little space to review the main work tasks of astronauts during navigation. This will be beneficial for understanding the aims and significance of the various specific measures of medical guarantees and medical supervision. Astronauts are responsible for the following tasks during space navigation:

- 1) Spaceship Operations and Management

Spaceships generally have two sets of independent operations system: one is an automatic or semi-automatic control system; the other is a "manual operations system" controlled by the astronaut. These two systems are usually independent of each other. Under most situations, spaceships work on an automatic or semi-automatic control system and astronauts need only supervise, manage and pay attention to whether there is a breakdown or places where it does not meet demands. Yet, sometimes astronauts must also carry out necessary procedural arrangements and data regulations. For example, when it is necessary for the spaceship to return or draw close to another spaceship astronauts must issue appropriate orders. Sometimes

these types of orders can also be given by the ground command system. A spaceship's manual control system generally uses an automatic control system as a type of reserve when there is a breakdown. Yet, in certain situations when it is necessary for people to carry out precision operations or mobile flight there is also the need for the manual control system. For example, when spaceships rendezvous, dock and soft land on the surface of the moon it is often necessary for astronauts to have a hand in part of the operations.

## 2) Fixed Position and Navigation

Airship navigation is usually automatically controlled or ground controlled yet when necessary astronauts must also participate in part of the work. In many situations when an airship is in a fixed position in space it is necessary for the astronaut to make a report to earth based on space observations and instrument indications. Navigation is generally carried out through communications between the astronaut and ground control center and by referring to the parameters of the star position. When there is a breakdown in the automatic control system and communications system the navigator must judge and deal with the situation based on his own astronavigation knowledge and space observations.

3) Report various circumstances with ground communications

4) Complete appointed air observations and scientific research tasks as well as other special tasks.

5) Examine and repair the various spaceship systems as well

as handle air breakdowns and mishaps including escape and rescue.

6) Deal with living, sanitation and resting during space navigation.

## Section Two    The Medical Selection of Astronauts

Being an astronaut is a special type of work. They sustain the effects of various special conditions during space navigation and carry out special work tasks and operations techniques during space navigation. This type of work requires relatively good physique, endurance and work ability. The task of selecting suitable people is very significant for raising astronaut quality, guaranteeing the completion of space navigation tasks and decreasing the astronaut elimination rate. The concrete selection of astronauts should be determined in terms of space navigation equipment, tasks and specific requirements yet the major fields can be summed up as follows:

1) Relatively good ideological consciousness and political character.

### 2) Routine Physical Examinations

The general age of astronauts should be between 25-35 years of age and the maximum should not exceed 45 years of age. Astronauts are usually selected from among fighter pilots and therefore at least routine physical examinations for fighter pilots should be given.

3) Examination of an astronaut's endurance to various

special conditons including overweightness, weightlessness, vibration, anoxia, decompression, high temperatures and low temperatures as well as testing endurance to motion sickness.

4) Test and appraise the cultural level (university or equivalent to university) and ability for theoretical study.

5) The appraisal of flight ability is generally carried out by a proper unit through investigation, testing and appraisal during actual fighter plane flight.

Aside from these, it should be pointed out that the training process of astronauts is itself a selection process. Those people who are not able to meet training requirements during the training period and are found not to be able to complete the necessary tasks for space navigation are eliminated and given other work.

### Section Three Medical Supervision of the Training Period

The primary task of the medical supervision during the training period is the maintenance of an astronaut's physical health and work abilities as well as the effects and progress of training.

#### 1. General Medical and Aerospace Medical Knowledge Education

##### 1. General Medical Knowledge Education

Astronauts should know and pay attention to how to correctly protect their own bodies, improve their own health and discover their own illnesses; they must accurately and with assurance report their subjective feelings and objective symptoms to the

medical personnel. This requires that the astronaut have a high political sense of responsibility. At the same time, they should also be educated in basic medical knowledge and besides holding classes and providing self study material physicians should offer a great deal of knowledge on medicine and sanitation to astronauts. If a navigator already has certain medical knowledge and sanitary habits then systematic classes are not totally necessary; if classes are given then they should be few and precise. Class time and style should be determined according to the specific conditions. We think that the distribution of class time can be set up as follows: 2-3 hours on preventing infectious diseases; 1-2 hours on food nutrition; 1-2 hours on sleep, motion physiology and stress physiology; 1-2 hours on emergency wounds.

## 2. Basic Knowledge of Aerospace Medicine

This basic knowledge allows an astronaut to understand the human body's reactions, adaptation, endurance and methods for overcoming stress factors in space navigation and can integrate an astronaut's practice for cabin equipment conditions and individual protective measures; classes and discussions go together and if well printed books are prepared then discussions can be primary and classes secondary. Moreover, practice and training should be integrated. Here we will sum up in the following several fields:

(1) General high altitude physiology which is the study of the effects of a high altitude environment on the human body;

(2) The mechanical and physiological basis of cabin pressurization, decompression and air supply;

(3) The structure, quality and other physiohygienic basis of an airtight space suit and helmet;

(4) The basic theories of vision and the visual problems in outer space;

(5) The physiological effects and methods of overcoming acceleration (overweightness);

(6) Auditory functions, equilibrium functions and vestibular autonomic nerve reactions and methods for overcoming them;

(7) Escape and rescue measures;

(8) The effects of extreme temperatures;

(9) The effects of toxic gases and waste gases;

(10) Cabin sanitation including ventilation, temperature, moisture, handling of wastes, sterilization etc.

Whether or not it is necessary to discuss these topics and how much time is to be used in discussing them should be determined by the actual needs. In short, it is necessary to integrate the principles of practice and training which can generally be carried out in 20 hours.

## 2. Regular Physical Examinations and Special Physical Examinations

### 1. Regular General Medical Examination

Here, the so-called general medical examination is not equivalent to the common examination as it has a specific aim



and focal point. Regular examinations can be carried out seasonally, semi-annually or annually. Their aim is to promptly discover any latent illnesses or unwell feelings that the examinee might have. At the time of the regular examination, the examinee should tell the physician his actual condition of health from defecation and urination, eating and drinking, sleep and work to all of the abnormal feelings that might occur. Generally, an astronaut must cooperate closely with the physician and speak truthfully about his own physical condition so that bodily changes can be promptly discovered. If an examinee consciously hides symptoms then some latent illnesses and hidden troubles might go unnoticed. Naturally, besides listening to the major complaints, a physician must also carry out a related objective target examination. For example:

- (1) A chest x-ray examination;
- (2) An examination of urine protein; urine haemoglobin and urine sugar;
- (3) Blood pressure and pulse and the recovery speed of blood pressure and pulse after exercise;
- (4) Examination of the electrocardiogram and the electrocardiogram after an exercise load;
- (5) Examination of the heart rate and blood pressure (systolic and diastolic pressure) in a positive position from lying flat to standing erect;
- (6) Hearing test;
- (7) Vision test including an examination of vision power, depth perception and heterophoria;
- (8) Balance functions: an examination using a revolving chair, two swings and four swings;

- (9) An examination of the nerves and limbs;
- (10) If progressive changes are found, a deeper specialized medical exam should be given; if no abnormalities are found then the specialized exam can be omitted

## 2. Preventative Diagnosis and Treatment of Illnesses

If a hidden illness or the beginnings of an illness are discovered during a regular medical examination then it is necessary to carry out definite diagnosis and treatment. When there is a surgical wound or other emergency accident (such as toxic gas poisoning) besides administering temporary first aid, the person should immediately be sent to the hospital for treatment.

Astronauts should understand how to perform simple sterilization, disinfecting, stop bleeding, tie bandages and temporarily handle fractures, dislocations, joint sprains etc. Prevention of illness is multifaceted and besides the physician looking at the situation and carrying out the required immunity inoculations and epidemic injection, it is very important that the navigator himself pay attention to individual hygiene.

## 3. Medical Supervision of Daily Life and Physical Exercise

The medical supervision of daily life includes three areas of problems :

### 1. Drinking, Eating and Nutritional Hygiene

This area of medical supervision is handled by a nutritionist. Firstly, they are responsible for supervising the sanitation of the kitchen and dining area. Secondly, all of

the physician's arrangements and orders concerning the navigator's food nutrition, cooking and nutritional distribution must be followed. The general requirements are: if individual eating habits are considered then it is also necessary to pay attention to nutritional hygiene. During the regular training period, there is generally only medium not very long physical activity so that the daily food heat need not exceed 3,000 kilocalories. It is not necessary to have special requirements for minerals and vitamins but they can be distributed according to general flight nutritional principles.

Yet, during space navigation life certainly has special characteristics and so work, rest and sleep time are not the same as on earth. Therefore, the amount of food consumed at one time, the time of the meals and the number of times per day one eats cannot be like the three meals per day on earth. Therefore, it is necessary on earth to establish new eating times and habits. For short time navigation (one or two days) it is naturally not necessary to become accustomed beforehand. Yet, if navigation time is long, for example in weeks, months or even years it is necessary to form new eating habits. By forming eating habits for space navigation on the ground one can avoid being unaccustomed to eating and drinking during the initial period of navigation as well as loss of body weight or bad digestion. Eating habits are not only eating time, number of times and amount, but even more important are the changes in food quality because during space navigation there

is a great discrepancy between the newly distributed food and the food in daily living. There is a process of getting accustomed to this type of food.

Airship food is all artificially concentrated and stored in packages. Nutrition doctors are responsible for supervising and appraising the processing, packaging and storing of food and ensuring that prior to the completion of navigation duties the food's nutrition, hygiene and flavor do not change and meet required standards. The quality sterilization and storage of drinking water is also examined and appraised by the nutrition doctor.

## 2. Sleep and Sleep Habits

Sleep is the best rest and proper sleep can raise work efficiency. Short time lack of sleep or insomnia does not have a great effect on work ability. If it exceeds 3 days this type of effect becomes noticeable, mainly in feelings of fatigue, work exhaustion and a desire for sleep. Normal people sleep about 8 hours per day at one time. Yet, it is not necessary to sleep 8 hours per day at one time. The use of other forms such as sleeping many times for short periods or sleeping during the day and working at night are fine but the problem lies in adaptation and habit. During the process of not being accustomed to becoming accustomed, there can occur the loss of physiological rhythm and disturbance of sleep.

Many astronauts do not follow the earth habit of sleeping 8 hours during a 24 hour day at one time but sleep short periods

many times wherein a total sleep time of only 5-6 hours/24 hours can satisfy requirements. The problem is whether or not forming the habit of sleeping many times for short periods beforehand on earth is advantageous to adapting to space navigation. According to foreign reports, there is a tendency to use this type of preparation and training for several days of space navigation. Further, sleeping while wearing a space-suit and helmet can also be included in this type of training.

### 3. Medical Supervision for General Physical Exercise

First is the arrangement of the type of exercise, method of exercise and time of exercise; second is medical supervision and the giving of first aid. As far as possible use various conditions, seasons and weather to arrange exercise. For example, swimming in the summer, ice skating and skiing in the winter, and camping and mountain climbing in the spring and autumn. It is even more important that it coordinate with other exercises and they be arranged together. It is best that during a certain period there is a unified exercise plan for each stage and that each item of training and exercise can be done in alternation. It must be remembered that work exercise and physical exercise are only one area of many types of training. There must be a focal point in the time distribution but the importance of this item cannot be overly emphasized while overlooking other exercises. The manpower work and physical exercise of an astronaut while on earth should not exceed medium strength so as to avoid obstructing other training items.

Physical exercise requires leading personnel medical supervision and medical guarantees. It must be carried out based on practical experience or exercise physiology and the guiding principles of exercise medicine so as to avoid dangerous accidents from occurring and causing unnecessary injuries. Physicians must also formulate under what circumstances it is not permissible for selected astronauts to do physical work and exercise so as to avoid excesses in training.

Section Four Medical Safeguards and Medical Supervision During the Preparatory Period Prior to Navigation

The length of the preparatory stage prior to navigation is difficult to accurately calculate. It should be determined according to the entire navigation plan and here it is tentatively assumed to be 3-6 months. During this period, besides usual life and medical supervision of general exercise, there is mainly the examination and appraisal of cabin equipment, individual protection and rescue, the life guarantee system and lifesaving measures as well as physical training for astronauts to do practice harnessing and special endurance. Below we will discuss these separately.

1. Medical Examination and Appraisal of Cabin Equipment

For the medical examination and appraisal of cabin equipment, besides the final examination prior to takeoff, it is also necessary to make a systematic examination to see whether or not it is up to standard.

Aside from the necessity to measure ion radiation in outer space, all of the other targets can be examined through ground tests. The examination method is to place an airtight cabin in an artificial environment and when the cabin environment regulating system is started it is best to have people to carry out examinations and appraisals in the airtight cabin. The environmental changes are measured for several hours or even longer so as to infer the possible changes for an even longer period of time. If the measuring time can be extended even longer its accuracy and inference will naturally be more reliable.

This examination and appraisal of the hygiene environment is the responsibility of the discipline of environmental hygiene. Moreover, it requires large scale equipment and measuring instruments and is carried out jointly by the engineering and technical personnel.

The ideal environmental parameters for the human body are a cabin medically appraised on a hygienic basis. Its specific parameters are as follows:

- (1) Temperature: generally 20-25°C, it is best not to be lower than 15°C or higher than 32°C;
- (2) Relative humidity: generally 40-45%, highest should not exceed 75%;
- (3) Air pressure: generally 760 millimeters on the mercury column, the lowest should not be lower than 400 millimeters on the mercury column;

(4) Oxygen partial pressure: generally 152-160 millimeters on the mercury column, it is best not to be lower than this number and not higher than 200 millimeters on the mercury column;

(5) Carbon dioxide partial pressure: generally 3-4 millimeters on the mercury column, it is best not to exceed 7.6 millimeters on the mercury column;

(6) Amount of drinking water required: generally 2 kiloliters/day (not including food moisture);

(7) Amount of food required: generally 2,500 kilocalories/day;

(8) Lighting: generally 5 millilambert;

(9) Noise level: generally 30 decibels; maximum does not exceed 80 decibels;

(10) Air movement generally 2.8 cubic meters per minute yet each minute should not be less than 2.5 cubic meters;

(11) Ion radiation: generally should be less than 40 milliröntgen per day;

(12) Harmful gases: required to be under the safety limit.

## 2. The Examination and Appraisal of the Individual Protective Harness and Lifesaving Equipment

This type of examination includes the airtight suit, ejection seat or life bag, parachute and life pack. The examination is a complex and difficult task and besides the above mentioned high temperature cabin, vacuum cabin and airtight cabin equipment, it is also necessary to carry out a complete examination and appraisal of other special equipment and conditions and



to cooperate with related specialists.

#### 1. Airtight Spacesuit and Helmet

Its structure and requirements differ according to the different aims for application. For example, the air supply of some helmets are joined to the ventilation of the suits wherein the pressure is completely identical to the gases (using pure oxygen). Some are completely separate, the helmet uses pure oxygen and a carbon dioxide absorbent and the suit ventilation uses compressed air or nitrogen so that after circulating the hot moist air leaks out of the suit. Some helmets have different pressures in the front and back parts, the pressure of the back part being higher. There are also some suits with ventilation which use airtight circulation. In them, the hot moist air goes through a cooler and water condenser which eliminates the heat and water and afterwards is again circulated back into the suit. Different designs are decided on the basis of the length of time used at one time and the outside environmental conditions. Yet, no matter what type it is, the human body requirements are the same. Here we will only bring forward an appraisal standard for the human body's general requirements. The detailed items and specific targets should be discussed and handled by related medical engineering departments. Below we introduce the basic requirements for the airtight suit and helmet.

(1) Suit section - requirements after filling it with air reaching 160-170 millimeters on the mercury column;

a. No leaking air or leaking gas does not exceed 20 millimeters per minute;

b. The wrist, elbow, knee and shoulder joints can move freely, there is no feeling of strain, there are no obstructions to operations and ejection work inside the cabin and there are no obstructions to various space activities and operations outside the cabin;

c. When there is a high temperature environment of 40°C, after wearing the suit and having ventilation for 1 hour the temperature under the clothes does not exceed 32°C, skin temperature does not exceed 34°C, the air's relative humidity does not exceed 60%; when doing medium muscle movement these numerical values can be maintained.

d. The surface layer of the suit can reflect over 85% of the radiation heat;

e. The heat insulation function is equal to 2.0 heat insulation units and the glove heat insulation function is equal to 1.5 heat insulation units;

f. The weight of the suit does not exceed 7 kilograms and the lighter the better. This indicates that it is a life-saving airtight suit. When the spacesuit is used under weightlessness or low weight conditions its weight is not limited to this. For example, some of the present suits used for leaving the cabin have weights over 15-16 kilograms (earth weight);

g. It is convenient to put on and take off. With the help of one person it can be completely put on in no more than 10 minutes (including the helmet and connecting tube); it is even

better if the astronaut were able to put it on himself.

(2) Helmet section - the partial air supplier as well as the carbon dioxide and water eliminator are joined. After the air is filled and there is airtightness the requirements are:

a. The pressure of the helmet's front section must be able to be maintained at about 160 millimeters on the mercury column and it is required that there be no leaking air;

b. The oxygen content can be maintained above 95% and the carbon dioxide content below 1%;

c. Neck movement should not feel strenuous and should not be too limited;

d. The field of vision on the left and right sides are 75°-80° each and the upper and lower are 35° and 45° respectively and cannot be any smaller;

e. The requirements for the function of the front light penetration plate are: 1) over 95% transmittance; 2) filter over 75% of the ultraviolet rays; 3) the cover can filter most of the infrared rays and ultraviolet rays and about 20% of the visible light; 4) after one-half hour in a -48°C environment there is still no mist or ice formation.

## 2. The Ejection Seat, Lifesaving Bag, Parachute and Life-saving Pack

The examination and appraisal of these few items are mainly the cooperative responsibility of the engineering department and astronauts because the movements of these types of

equipment are completely automated. In the examination, then, the essential point is to examine their reliability. Yet, the medical personnel should also participate so that when there are medical problems or problems that do not coincide with human physiological demands, they can do consulting work or propose ideas. Actually, when there is cabin practice or individual protective harness practice they should be able to discover problems.

### 3. Airship Cabin Practice and Simulator Training

This is a very important specialized training course and part of the technical course study can be combined with it. It is first of all necessary to get accustomed to the cabin instruments and instrument layout as well as the communications system and connection, and later study control piloting and course flights. After this type of study one is taken to fly by the instructor and later makes a solo flight. If the astronaut is selected from among the experienced aircraft pilots then they are already familiar with aviation training and this it is not necessary for them to repeat it. Nevertheless, there are noticeable differences between an airship's instrument layout, the various environmental control equipment and individual protective equipment and that of an aircraft. Among them, the greatest difference is in the control system. Because of this, prior to entering simulated cabin practice it is first necessary to be familiar with the airship's structure, cabin equipment, cabin

instruments, flight orbits, posture control and operating methods.

The measurements and layout of the inside and outside of the simulated cabin are identical to that of a real cabin. Moreover, it can make 4-5 free angle (including shifts and turns) movements and the pilot carries out operations to realize these movements. The cabin's main instruments and other indicators can all change in accordance with the flight orbit and airship posture and thus indicate the reading. This type of simulator is very close to an airship's real cabin. The construction of a fixed non-moveable simulated cabin is not very expensive, its construction time is not very long and this type of fixed simulated cabin can satisfy astronaut practice needs. Yet, it should be pointed out that it is not sufficient to only use the fixed simulator for navigation training so that an airtight airship environment and airship movement environment must also be constructed. These types of environments can not only be used for training astronauts but can also be used to appraise and test airship cabin equipment. Prior to takeoff the single items of airship flight training must be carried out together so as to reach the goal of comprehensive training.

The problem lies in whether this type of cabin can be used to train astronauts for weightlessness. In order to resolve this problem a fast speed aircraft is used to make parabolic flight (weightless flight) to carry out training. Moreover, the training should be repeated many times. Equipment for training vestibular

functions can be used for posture balance training. Special machines can also be arranged so that the people and instruments can both be tested for posture unsteadiness.

#### 4. Practice and Physical Training for Individual Protective Harnessing

This includes the putting on, taking off and use of the spacesuit and helmet, and also involves ejection posture and landing speed. After using the above mentioned equipment for theoretical education in aerospace medical science, the use of peripheral studies, education, work and changes are carried out to allow the astronaut to control the main functions of these types of equipment as well as methods for its accurate use.

#### Section Five    The Medical Supervision of the Preparatory Stage Prior to Launch

This stage lasts about 2 weeks to 1 month. In this stage, the medical tasks include the following major items:

##### 1. Life Management and Health Guarantees

During this period, the work can be tense because it is close to launching. The physician's job should be to carry out good ideological work for the astronaut, calm him as much as possible, make sure he has enough sleep and when necessary a suitable sedative can be used.

The physical training of astronauts allows them to get accustomed to drinking, eating and sleeping in flight and it is best started 2 weeks prior to takeoff. This is because a certain

amount of time is required to form habits and so the earlier one starts the better; prior to forming habits there can possibly also be an affect on normal appetite and sleep. Further, excessive physical exercise and tense work should be avoided. It is also necessary during this period to strengthen life sanitation management so as to avoid the occurences of illnesses such as coughs, colds, bad digestion and constipation.

## 2. Cabin Sanitation Examination and Epidemic Prevention Sterilization Prior to Takeoff

The area involved in the cabin sanitation examination is very broad so that here we will only give an outline. The problem of epidemic prevention sterilization for short time navigation is not great because the source of the epidemic carried by humans or in the equipment can only show effects after a dormancy period in the human body. If navigation time is relatively long then it is very necessary to administer immunity inoculations.

### 1. The Problem of Epidemic Prevention Sterilization

It is relatively easy to administer epidemic prevention inoculations to people but cabin sterilization is a more difficult matter. The use of aerosol spray to eliminate insects and other arthropods is not difficult but certain bacteria, gemma and viruses are not easy to thoroughly eliminate. This is because the resistance of certain microorganisms to disinfectants is especially strong and furthermore they are often stuck

in the crevices of the equipment and instruments thus making them hard to reach with aerosol. Only by using high pressure steam can a relatively high disinfecting rate be attained; yet high temperature steam can also harm the equipment so that this is a contradiction. From a purely medical point of view, it is only necessary to not cause the occurrence of infectious diseases which can be considered reaching the goal of disinfecting. It has been practically proven that the use of preventative inoculations can resolve this problem and if there is also spray disinfecting and ultraviolet lamp irradiation (it cannot be used often because it can change oxygen into ozone) this can even better meet the requirements. The existence of non-contagious gemma and other microorganisms need not be given overconsideration. The absolute elimination of bacteria is not only not necessary but is actually sometimes harmful.

## 2. The Examination of Harmful Gases and Harmful Steam

There are several hundred types of harmful gases and steam but it is not necessary to appraise each type. It is possible that various harmful gases gradually accumulate in the airtight cabin and from the results of measurements several hours after being sealed, inferences can be made. These obtained results are not yet reliable and so there must be actual measurement at all times. It is very difficult to carry out an independent analysis of each type of harmful gas yet the common physical chemistry properties of the various harmful gases can be sought out, go through filtering and be absorbed. Afterwards, they can



again be separated out from the filtered and absorbed materials and be comprehensively appraised. In order to survey the speed and effect of their long time accumulation, long time monitoring or fixed time monitoring methods can be adopted. Aside from the monitoring of instruments by the astronauts themselves the telemetering method can also be used.

### 3. The Examination of Food Rations, Drinking Water and the Handling of Wastes During Navigation

Navigation food rations require the use of special concentrating and drying processes. At present, food can still not be produced on an airship and so all of it must be carried from earth. The physician's responsibilities lie in appraising a standard for food; at the time of examination, it is necessary to cooperate with the scientific research and production departments. Related physicians must also understand whether or not the storage methods for food and drinking water on the airship are rational so that they can present ideas for improvement when needed; they must also understand the source of the drinking water. Drinking water is not convenient to keep for a long time and even if it is stored in a low temperature tank it still needs periodic disinfecting. It is necessary to have chemical tests of samples for recovered drinking water which is appraised according to the general requirements of public sanitation. This is only possible when there are chemical test equipment and physicians in the airship but generally speaking these tests can only be done in ground simulated conditions.

The handling of pollutants is a problem which cannot be neglected in airship sanitation engineering. Pollutants include human excrement as well as waste materials. The medical personnel should appraise whether or not the handling of pollutants meets the requirements.

### 3. The Preparation and Medical Requirements for the Medicine Bag and First Aid Bag

In space navigation certain medicines should be prepared because at present there is still not much experience in space navigation and rarely are there mature plans. Generally, it can be discussed according to specific circumstances by responsible physicians and astronauts. If space and weight permit it, more drugs can be taken. One day prior to airship launching the physician talks with the astronauts and gives instructions on certain medicines and sanitation. He emphasizes the need for the astronauts to become aware of problems that occur in their own bodies and the need to become familiar with the conditions and methods of using emergency drugs. It is also necessary for them to always report to earth so that they can handle matters at the proper time.

### Section Six Medical Guarantees and Medical Supervision During Navigation

The medical guarantees and medical supervision during navigation can only draw support from physiological functions, the related physical target telemetering and radio communication

for completion.

Biological functions and human subjective feelings can be transmitted to earth by means of radio telemetering, radio communications and television. The radio telemetering uses a sensor to measure the body's biological electric changes or uses a sensing transducer to measure the various life activities of the body such as respiration, pulse, heart sounds, blood pressure etc.; or uses resistance changes to measure the body temperature, skin temperature, blood vessel expansions and contractions, blood concentration etc. In the past, physiological function telemetering always tested the above mentioned items separately. To sum up, it can be said that not all targets are needed for each time of navigation and selection should be done according to the requirements of the tasks. Starting from the subject's waking, sleeping, motor coordination and stimulation reaction, the electrocardiogram, blood pressure, electro-myogram, eye movement and respiration are all very useful, yet not all of them are necessarily used at the same time so that it is necessary to decide according to need.

At present, the physiological telemeter techniques are already quite advanced, especially in the areas of micro-miniaturization and the elimination of noise disturbances. Physiological signs cannot be used independently as an antenna but together with many physical signs they can act as an antenna. Because of this, after the signs are received by earth

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it is still necessary to undergo analysis procedure. Even if the analysis procedure is completely electronic and automatic yet because of the mutual relationship between the physiological targets and the physical factors, in the end it is still necessary for people to carry out analysis and make judgement.

An astronaut's expression and partial movements can be seen from the television changes. This has great reference value for discriminating an astronaut's movements at the time.

The most useful information for medical supervision is direct radio communications. This is the most important method of present telemeter supervision. Medical personnel gain information on the main complaints of astronauts through telephone communications and furthermore they gain other related information with the aid of telephone communication. The doctors can issue orders based on this and inform the astronauts of related matters to pay attention to.

From the view of the physiological telemeter material obtained in the past, none of the target changes during navigation had any excessive physiological stimulation reactions and therefore one target could not be taken independently as a basis for medical supervision. Even if several physiological targets and physical targets are combined and displayed it is still difficult to make a quick judgement and conclusion. From this, we think that the key problem lies in electronic and automatic diagnosis. Only if sufficiently fast diagnostic time is strived for can they opportunely guide medical supervision without error.

At present, hospitals already have electronic diagnostic instruments and so space navigation can also employ electronic diagnostic equipment. If we make separate diagnosis beforehand based on the highs and lows of the various physiological targets, the related physical parameters of the cabin and the possible quality of television and radio communications, and sort them out in an electronic computer then after each item of physiological and physical information reaches earth and is put into the computer the physician can immediately make a diagnosis and judgement. In this way the physician can carry out medical supervision by giving oral commands to the astronauts and so not miss the opportunity. The tasks of the physician can then be greatly decreased and at the same time they can have more time to consider the main complaints of the astronauts and to report and discuss other situations. Even if the material of the physiological functions telemeter cannot promptly act as the basis for medical supervision during navigation it is still very valuable for future medical guarantees.

Section Seven Medical Guarantees for Returning to Earth and Observations on the After Effects of Navigation

Medical personnel must do well in all of the preparations needed for meeting the triumphant return of the astronauts. It is necessary to prepare effective rescue communication instruments, rescue equipment and drugs in the recovery area so that if by chance there is an accident they can quickly and

effectively render first aid.

After landing, it is usually necessary to carry out a medical examination so as to determine the needed treatment and rest. Even more important are the physiological and physiochemical examinations to observe the after effects of navigation. This will provide an even more solid basis for future navigation and medical guarantees. The problems discovered based on past work are:

- 1) There was an 8-15% loss of bone calcium and other minerals in several days of navigation;

- 2) A drop in body weight and a serious loss of water - body weight loss was over 4 kilograms;

- 3) In positive posture tests there was an irregular weakening of endurance which appeared in a drop of blood pressure, quickening of heart rate and collapse in more serious cases (the positive posture endurance decreased) after going from a lying down to a standing position;

- 4) A decrease in red blood cells and blood volume decreased;

- 5) A great deal of protein was destroyed and there was much urine;

Although these symptoms can be eliminated after a short period of rest yet whether it will be this way in future longer navigation still awaits further research. Because of this, the physiochemical and physiological examinations have practical significance for navigation medical guarantees. At present,

there are still not many materials on this field and thus awaits further and deeper research.

If there are medical personnel who follow an airship's flight and whenever necessary gather medical observation materials and carry out medical supervision, then the situation will be even better. It can be imagined that the length of future space navigation will be calculated in years and thus it is even more necessary to set up airship chemical laboratories and provide specialized medical personnel.

Medical personnel must make medical conclusions based on the experiences of each navigation including the work of each ground preparatory period so as to search for training, physical exercise and medical guarantees as well as patterns for medical supervision.

# APPENDIX

## I. Commonly Used Measure Units and Their Conversions

1 类别	5 采用的单位名称	32 原用名称	36 代号	37 对主单位的比	61 折合市制
2 长度	1 微米	33 公基	$\mu$	1/1000000	
	2 毫米		mm	1/100000	
	3 丝米		dmm	1/10000	
	4 毫米	34 公厘	mm	1/1000	62 3市厘
	10 厘米	35 公分	cm	1/100	63 3市分
	1 分米	36 公寸	dm	1/10	64 3市寸
	12 米	37 公尺	m	主单位	65 3市尺
	13 十米	38 公丈	dam	10	66 3市丈
	14 百米	39 公引	hm	100	
	15 公里(千米)	40 公里	km	1000	67 2市里
3 重量 (质量单位名称同)	16 毫克	41 公丝	mg	1/1000000	
	17 厘克	42 公毫	cg	1/100000	
	18 分克		dg	1/10000	68 2市厘
	19 克	43 克(公分)	g	1/1000	69 2市分
	20 十克	44 公钱	dag	1/100	70 2市钱
	21 百克	45 公两	hg	1/10	71 2市两
	22 公斤	46 千克	kg	主单位	72 2市斤
	23 公担	47 公担	q	100	73 2市担
	24 吨	48 公吨	t	1000	
4 容量	25 毫升	49 公撮	ml	1/1000	
	26 厘升	50 公勺	cl	1/100	
	27 分升	51 公合	dl	1/10	74 1市合
	28 升	52 公升	l	主单位	75 1市升
	29 十升	53 公斗	dal	10	76 1市斗
	30 百升	54 公石	hl	100	77 1市石
	31 千升	55 公秉	kl	1000	

注：上表系根据1959年6月25日国务院公布的“统一公制计量单位中之名称方案”整理而成。

Table 1



Table 1 (1) Standard Metric System Measure Unit

1. Category
2. Length
3. Weight (same as mass unit)
4. Volume
5. Name of unit used
6. Micron
7. 1/100000 meter
8. 1/10000 meter
9. Millimeter
10. Centimeter
11. Decimeter
12. Meter
13. 10 meters
14. 100 meters
15. Kilometer
16. Milligram
17. Centigram
18. Decigram
19. Gram
20. 10 grams
21. 100 grams
22. Kilogram
23. Quintal
24. Ton
25. Milliliter
26. Centiliter
27. Deciliter
28. Liter
29. 10 liters
30. 100 liters
31. Kiloliter
32. Name originally used
33. Micron
34. Millimeter
35. Centimeter
36. Decimeter
37. Meter
38. 10 meters
39. 100 meters
40. Kilometer
41. Milligram
42. Centigram
43. Gram
44. 10 grams
45. 100 grams
46. Kilogram
47. Quintal
48. Metric ton
49. Milliliter

50. Centiliter
51. Deciliter
52. Liter
53. 10 liters
54. 100 liters
55. Kiloliter
56. Symbol
57. Ratio of major unit
58. Major unit
59. Major unit
60. Major unit
61. Converted to Chinese market system
62. 3 li
63. 3 fen
64. 3 cun
65. 3 chi
66. 3 zhang
67. 2 li
68. 2 li
69. 2 fen
70. 2 qian
71. 2 liang
72. 2 jin
73. 2 dan
74. 1 he
75. 1 sheng
76. 1 dou
77. 1 shi
78. Note: the above table is based on the "name plans of the standard metric system measure units" published by the State Council on June 25, 1956.

1 字 首	2 国际字头	3 英文字头	4 俄文字头	5 中文字头	20倍 数
atto	a			6 微微微	$10^{-18}$
femto	f			7 毫微微	$10^{-15}$
pico	p	μA	Н (НННН)	8 微微微	$10^{-12}$
nano	n	mA	Н (НННН)	9 毫微微	$10^{-9}$
micro	μ	μ	мк	10 微	$10^{-6}$
milli	m	m	м	11 毫	$10^{-3}$
centi	c	c	с	12 厘	$10^{-2}$
deci	d	d	д	13 分	$10^{-1}$
deka	da	D	да	14 十	$10^1$
hecto	h	h	г	15 百	$10^2$
kilo	k	k	к	16 千	$10^3$
mega	M	M	М	17 兆	$10^6$
giga	G	G	Г	18 千兆	$10^9$
tera	T	T	Т	19 兆兆	$10^{12}$

Table 2

Table 2 (2) Table of Commonly Used Word Prefixes for Multiple and Fractional Units

1. Prefix
2. International prefix
3. English prefix
4. Russian prefix
5. Chinese prefix
6. Micro-micro-micro
7. Milli-micro-micro
8. Micro-micro
9. Milli-micro
10. Micro-
11. Milli-
12. Centi-
13. Deci-
14. 10
15. 100
16. Kilo-
17. Mega-
18. Kilomega-
19. Mega-mega-
20. Multiple

1 公制变英制	2 英制变公制
<b>2 长 度</b>	
3 1 厘米 = 0.393701 英寸	26 1 英寸 = 2.54 厘米
4 1 厘米 = 0.032808 英尺	27 1 英尺 = 30.48 厘米
5 1 米 = 1.09361 码	28 1 码 = 0.9144 米
6 1 公里 = 0.621371 英里	29 1 英里 = 1.60934 公里
7 1 公里 = 0.5596 海里	30 1 海里 = 1.852 公里
<b>3 面 积</b>	
9 1 厘米 <sup>2</sup> = 0.155000 英寸 <sup>2</sup>	31 1 英寸 <sup>2</sup> = 6.4516 厘米 <sup>2</sup>
10 1 米 <sup>2</sup> = 1.19599 码 <sup>2</sup>	32 1 码 <sup>2</sup> = 0.836127 米 <sup>2</sup>
11 1 公里 <sup>2</sup> = 0.386108 英里 <sup>2</sup>	33 1 英里 <sup>2</sup> = 2.58999 公里 <sup>2</sup>
12 1 公顷 = 2.47105 英亩	33a 1 英亩 = 4046.86 米 <sup>2</sup>
<b>13 体积和容积</b>	
14 1 厘米 <sup>3</sup> = 0.0610237 英寸 <sup>3</sup>	34 1 英寸 <sup>3</sup> = 16.3871 厘米 <sup>3</sup>
15 1 厘米 <sup>3</sup> = 3.532 × 10 <sup>-5</sup> 英尺 <sup>3</sup>	35 1 英尺 <sup>3</sup> = 2.832 × 10 <sup>4</sup> 厘米 <sup>3</sup>
16 1 米 <sup>3</sup> = 1.30795 码 <sup>3</sup>	36 1 码 <sup>3</sup> = 0.764555 米 <sup>3</sup>
17 1 升 = 1.75980 品特(英)	37 1 品特(英) = 0.568 升
18 1 升 = 0.2642 加仑(美)	38 1 加仑(美) = 3.7853 升
19 1 升 = 0.22 加仑(英)	39 1 加仑(英) = 4.546 升
<b>20 质 量</b>	
21 1 克 = 0.0352740 盎司	40 1 盎司 = 28.3495 克
22 1 公斤 = 2.20462 磅	41 1 磅 = 0.45359237 公斤
23 1 公斤 = 0.984205 × 10 <sup>-3</sup> 吨(英)(长吨)	42 1 长吨(英) = 1016.05 公斤
24 1 公斤 = 1.1023 × 10 <sup>-3</sup> 吨(美)(短吨)	43 1 短吨(美) = 907.2 公斤

Table 3a continued on next page

44 公制变英制

46 英制变公制

力

- 44 1 公斤力 = 2.20462 磅力  
= 70.9316 磅达  
43 1 公斤力 = 9.80665 牛顿  
42 1 牛顿 = 0.224809 磅力  
= 7.23301 磅达

- 47 1 磅力 = 0.453592 公斤力  
= 4.44822 牛顿  
48 1 磅达 = 0.0140981 公斤力  
= 0.138255 牛顿  
49 1 磅力 = 32.1744 磅达

功、能和热

- 50 1 焦耳 = 0.737562 英尺·磅力  
= 23.7304 英尺·磅达  
51 1 焦耳 =  $0.9481 \times 10^{-3}$  Btu  
52 1 千卡 = 3.968 Btu  
53 1 千瓦·小时 = 3413 Btu

- 70 1 英尺·磅力 = 1.35582 牛顿·米  
71 1 英尺·磅达 = 0.0421401 牛顿·米  
72 1 Btu =  $1.055 \times 10^3$  焦耳  
73 1 Btu = 0.252 千卡  
74 1 Btu =  $2.930 \times 10^{-4}$  千瓦·小时

热 容

- 55 1 卡/克·度(°C) = 1.000 Btu/磅·度(°F)

- 75 1 Btu/磅·度(°F) = 1.000 卡/克·度(°C)

热 导 率

- 57 1 千卡/米·小时·度(°C)  
= 0.672 Btu/英尺·小时·度(°F)

- 76 1 Btu/英尺·小时·度(°F)  
= 1.488 千卡/米·小时·度(°C)

粘 度

- 59 1 厘泊 = 2.419 磅/小时·英尺

- 77 1 磅/小时·英尺 = 0.4134 厘泊

压 力

- 61 1 大气压 = 14.696 磅/英寸<sup>2</sup>  
62 1 公斤/厘米<sup>2</sup> = 14.223 磅/英寸<sup>2</sup>  
63 1 厘米汞柱 = 0.1934 磅/英寸<sup>2</sup>

- 78 1 磅/英寸<sup>2</sup> =  $6.895 \times 10^{-2}$  大气压  
79 1 磅/英寸<sup>2</sup> = 0.070307 公斤/厘米<sup>2</sup>  
80 1 磅/英寸<sup>2</sup> = 5.1715 厘米汞柱

密 度

- 65 1 克/厘米<sup>3</sup> = 62.43 磅/英尺<sup>3</sup>

- 81 1 磅/英尺<sup>3</sup> = 0.01602 克/厘米<sup>3</sup>

82 ● 英国采用 1.8532 公里作为 1 海里。

83 ● Btu 为英制热量单位。

(3) Physical Unit Conversion Tables

Table 3a 1. English and Metric Unit Conversion Factor Table

1. Metric system converted to British System
2. Length
3. 1 centimeter = 0.393701 inches
4. 1 centimeter = 0.032808 feet
5. 1 meter = 1.09361 yards
6. 1 kilometer = 0.621371 miles
7. 1 kilometer = 0.5396 nautical miles
8. Area
9. 1 centimeter<sup>2</sup> = 0.155000 inches<sup>2</sup>
10. 1 meter<sup>2</sup> = 1.19599 yards<sup>2</sup>
11. 1 kilometer<sup>2</sup> = 0.386103 miles<sup>2</sup>

12. 1 hectare=2.47105 acres
13. Volume and Capacity
14. 1 centimeter<sup>3</sup>=0.0610237 inches<sup>3</sup>
15. 1 centimeter<sup>3</sup>=3.532 x 10<sup>-5</sup> feet<sup>3</sup>
16. 1 meter<sup>3</sup>=1.30795 yards<sup>3</sup>
17. 1 liter=1.75980 pints (British)
18. 1 liter=0.2642 gallons (American)
19. 1 liter=0.22 fallons (British)
20. Mass
21. 1 gram=0.0352740 ounces
22. 1 kilogram=2.20462 pounds
23. 1 kilogram=0.984205 x 10<sup>-3</sup> tons (British)  
(long tons)
24. 1 kilogram=1.1023 x 10<sup>-3</sup> tons (American)  
(short tons)
25. British system converted to metric system
26. 1 inch=2.54 centimeters
27. 1 foot=30.48 centimeters
28. 1 yard=0.9144 meters
29. 1 mile=1.60934 kilometers
30. 1 nautical mile<sup>F.N.1</sup>=1.852 kilometers
31. 1 inch<sup>2</sup>=6.4516 centimeters<sup>2</sup>
32. 1 yard<sup>2</sup>=0.836127 meters<sup>2</sup>
33. 1 mile<sup>2</sup>=2.58999 kilometers<sup>2</sup>
- 33a. 1 acre=4046.86 meters<sup>2</sup>
34. 1 inch<sup>3</sup>=16.3871 centimeters<sup>2</sup>
35. 1 foot<sup>3</sup>=2.832 x 10<sup>4</sup> centimeters<sup>3</sup>
36. 1 yard<sup>3</sup>=0.764555 meters<sup>3</sup>
37. 1 pint (British)=0.568 liters
38. 1 gallon (American)=3.7853 liters
39. 1 gallon (British)=4.546 liters
40. 1 ounce=28.3495 grams
41. 1 pound=0.45359237 kilograms
42. 1 long ton (British)=1016.05 kilograms
43. 1 short ton (American)=907.2 kilograms
44. Metric system converted to British System
45. System Force
46. 1 kilogram force=2.20462 pounds force=  
70.9316 pounds
47. 1 kilogram force=9.80665 Newton
48. 1 Newton=0.224809 pounds force=7.23301 pounds
49. Power energy and heat
50. 1 joule=0.737562 feet·pounds force=23.7304  
feet·pounds

51. 1 joule =  $0.9481 \times 10^{-3}$  Btu<sup>F.N.2</sup>
52. 1 kilocalorie = 3.968 Btu
53. 1 kilowatt·hour = 3413 Btu
54. Heat capacity
55. 1 calorie/gram·degree (°C) = 1.000 Btu/pound·degree (°F)
56. Heat conduction
57. 1 kilocalorie/meter·hour·degree (°C) = 0.672 Btu/feet·hour·degree (°F)
58. Viscosity
59. 1 centipoise = 2.419 pounds/ hour·feet
60. Pressure
61. 1 atmospheric pressure = 14.696 pounds/inch<sup>2</sup>
62. 1 kilogram/centimeter<sup>2</sup> = 14.223 pounds/inch<sup>2</sup>
63. 1 centimeter on mercury column = 0.1934 pounds/inch<sup>2</sup>
64. Density
65. 1 gram/centimeter<sup>3</sup> = 62.43 pounds/feet<sup>3</sup>
66. British system converted to metric system
67. 1 pound force = 0.453592 kilograms force = 4.44822 Newton
68. 1 pound = 0.0140981 kilograms force = 0.138255 Newton
69. 1 pound force = 32.1744 pounds
70. 1 foot·pound force = 1.35582 Newton·meter
71. 1 foot·pound = 0.0421401 Newton·meter
72. 1 Btu =  $1.055 \times 10^3$  joule
73. 1 Btu = 0.252 kilocalories
74. 1 Btu =  $2.930 \times 10^{-4}$  kilowatts·hour
75. 1 Btu/pound·degree (°F) = 1.000 calories/grams·degree (°C)
76. 1 Btu/feet·hour degree (°F) = 1.488 kilocalories/meter·hour degree (°C)
77. 1 pound/hour·feet = 0.4134 centipoise
78. 1 pound/inch<sup>2</sup> =  $6.805 \times 10^{-2}$  atmospheric pressure
79. 1 pound/inch<sup>2</sup> = 0.070307 kilograms/centimeter<sup>2</sup>
80. 1 pound/inch<sup>2</sup> = 5.1715 centimeters on mercury column
81. 1 pound/inch<sup>3</sup> = 0.01602 grams/centimeter<sup>3</sup>
82. F.N. 1 - England uses 1.8532 kilometers as 1 nautical mile
83. F.N. 2 - Btu is a heat unit of the British system

1 公制质量工程单位 = 9.80665 公斤

2 英制质量工程单位 (斯勒格 Slug) = 32.1740 磅

3 1 微米 ( $\mu$ ) =  $10^{-6}$  米

4 1 埃 ( $\text{\AA}$ ) =  $10^{-10}$  米

5 1 X 单位 (XU) =  $10^{-11}$  厘米

6 1 费米 (fm) =  $10^{-13}$  厘米

7 1 微英寸 ( $\mu\text{in.}$ ) =  $10^{-6}$  英寸

8 1 毫英寸 (milli-inch) =  $10^{-3}$  英寸

9 1 密耳 (mil) =  $10^{-3}$  英寸

10 1 光年 =  $5.880 \times 10^{12}$  哩

11 1 秒差距 (parsec) = 3.263 光年

12 1 吧 =  $10^{-28}$  米<sup>2</sup>

13 1 托 = 1/760 标准大气压 = 1 毫米汞柱

14 1 巴 (b) =  $10^6$  达因/厘米<sup>2</sup>

15 1 毫巴 = 0.7501 托

$$16 \text{ 温度: } ^\circ\text{C} = (^{\circ}\text{F} - 32) / 1.8 = (^{\circ}\text{F} - 32) \times \frac{5}{9}$$

$$^{\circ}\text{F} = 1.8^{\circ}\text{C} + 32 = 9/5^{\circ}\text{C} + 32$$

$$^{\circ}\text{K} = ^\circ\text{C} + 273.16$$

17 ● 更准确地说, 1 X 单位 =  $1.00201 \times 10^{-8}$  埃。

Table 3b 2. Commonly Seen Unit Conversions

1. 1 metric mass engineering unit = 9.80665 kilograms
2. 1 British system mass engineering unit (Slug) = 32.1740 pounds
3. 1 micron ( $\mu$ ) =  $10^{-6}$  meters
4. 1 angstrom (A) =  $10^{-10}$  meters
5. 1 X unit (XU) =  $10^{-11}$  centimeters
6. 1 fermi (fm) =  $10^{-13}$  centimeters
7. 1 micro-inch ( $\mu\text{in.}$ ) =  $10^{-6}$  inches
8. 1 milli-inch =  $10^{-3}$  inches
9. 1 mil =  $10^{-3}$  inches
10. 1 light year =  $5.880 \times 10^{12}$  miles
11. 1 parsec = 3.263 light years
12. 1 barn =  $10^{-28}$  meters
13. 1 ton = 1/760 standard atmospheric pressure = 1 millimeter on mercury column
14. 1 bar (b) =  $10^6$  dyne/centimeter<sup>2</sup>
15. 1 millibar = 0.7501 ton
16. Temperatures
17. F.N.<sub>3</sub><sup>1</sup> - even more accurate, 1X unit =  $1.00201 \times 10^{-8}$  angstrom

1 量	2 数值	3 单位	4 误差, ppm
2 1 千克	6.609538 (24)	$10^{20}$ 兆电子伏	16 4.4
3 1 原子质量单位	931.4812 (52)	兆电子伏	17 5.5
4 电子质量	0.5110041 (16)	兆电子伏	18 3.1
5 质子质量	938.2592 (52)	兆电子伏	19 5.5
6 中子质量	939.5527 (52)	兆电子伏	20 5.5
7 1 电子伏	1.6021917 (70)	$10^{-10}$ 焦耳	21 4.4
		$10^{-12}$ 尔格	22
	2.4179859 (81)	$10^{14}$ 赫	23 3.3
	8.065485 (27)	$10^5$ 米 $^{-1}$	24 3.3
		$10^3$ 厘米 $^{-1}$	25
	1.160485 (49)	$10^4$ °K	42
8 能量-波长换算	1.2398541 (41)	$10^{-6}$ 电子伏·米	26 3.3
9 里德伯常数, $R_1$	2.179914 (17)	$10^{-18}$ 焦耳	27 7.6
		$10^{-11}$ 尔格	28
	13.605826 (45)	电子伏	29 3.3
	3.2898423 (11)	$10^{10}$ 赫	30 0.35
	1.678936 (67)	$10^5$ °K	43
10 玻尔磁子, $\mu_B$	5.788381 (18)	$10^{-8}$ 电子伏/忒斯拉	31 3.1
	1.3996108 (43)	$10^{10}$ 赫/忒斯拉	32 3.1
	48.68598 (14)	米 $^{-1}$ ·忒斯拉 $^{-1}$	33 3.1
		$10^{-2}$ 厘米 $^{-1}$ ·忒斯拉 $^{-1}$	34
	0.671733 (29)	°K/忒斯拉	35 43
11 核磁子, $\mu$	3.152526 (21)	$10^{-8}$ 电子伏/忒斯拉	36 6.8
	7.622700 (42)	$10^8$ 赫/忒斯拉	37 5.5
	2.542659 (14)	$10^{-2}$ 米 $^{-1}$ ·忒斯拉 $^{-1}$	38 5.5
		$10^{-4}$ 厘米 $^{-1}$ ·忒斯拉 $^{-1}$	39
	3.65846 (16)	$10^{-4}$ °K/忒斯拉	40 44
12 气体常数, $R_0$	8.20562 (35)	$10^{-2}$ 米 $^3$ ·大气压/千摩尔·°K	41 42
13 理想气体标准体积, $V_0$	22.4136	米 $^3$ /千摩尔	42

Table 3c 3. Energy Conversion Factors (the numbers in brackets are the standard deviation)

1. Quantity
2. 1 kilogram
3. 1 atomic mass unit
4. Electron mass
5. Proton mass
6. Neutron mass
7. 1 electron-volt
8. Energy-wavelength conversion
9. Rydberg constant,  $R_1$
10. Bohr magneton,  $\mu_B$
11. Nuclear magneton,  $\mu$
12. Gas constant,  $R_0$

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13. Ideal gas standard volume,  $V_0$
14. Numerical value
15. Unit
16.  $10^{29}$  megaelectron-volts
17. Megaelectron-volts
18. Megaelectron-volts
19. Megaelectron-volts
20. Megaelectron-volts
21.  $10^{-19}$  joule
22.  $10^{-12}$  erg
23.  $10^{14}$  hertz
24.  $10^5$  meters<sup>-1</sup>
25.  $10^3$  centimeters<sup>-1</sup>
26.  $10^{-6}$  electron-volts·meters
27.  $10^{-18}$  joule
28.  $10^{-11}$  erg
29. Electron-volts
30.  $10^{15}$  hertz
31.  $10^{-5}$  electron-volts/tesla
32.  $10^{10}$  hertz/tesla
33. Meter<sup>-1</sup>·tesla<sup>-1</sup>
34.  $10^{-2}$  centimeter<sup>-1</sup>·tesla<sup>-1</sup>
35. °K/tesla
36.  $10^{-8}$  electron-volts/tesla
37.  $10^6$  hertz/tesla
38.  $10^{-2}$  meters<sup>-1</sup>·tesla<sup>-1</sup>
39.  $10^{-4}$  centimeter<sup>-1</sup>·tesla<sup>-1</sup>
40.  $10^{-4}$  °K/tesla
41.  $10^{-2}$  meters<sup>3</sup>·atmospheric pressure/kilomole·°K
42. Meters<sup>3</sup>/kilomole
43. Error, ppm

See next page for Table 3d

物理量	实用单位	23 绝对单位制			
		24 有理化的MKSA单位	38 CGS电磁单位	49 CGS静电单位	
单位	单位	单位	单位	单位	倍数
2 能	焦耳(J)	焦耳(J)	尔格	尔格	$\times 10^{-7}$
3 功率	瓦特(W)	瓦特(W)	尔格/秒	尔格/秒	$\times 10^{-7}$
4 电量	库仑(C)	库仑(C)	绝对库仑	静电库仑	$\times 10^9$
5 电极化强度	库仑/厘米 <sup>2</sup>	库仑/厘米 <sup>2</sup>	绝对库仑/厘米 <sup>2</sup>	静电库仑/厘米 <sup>2</sup>	$\times 10^9$
6 电位	伏特(V)	伏特(V)	绝对伏特	静电伏特	$\times 10^9$
7 电场强度	伏特/厘米	伏特/厘米	绝对伏特/厘米	静电伏特/厘米	$\times 10^9$
8 介电常数		法拉(F)	绝对法拉	厘米或静电法拉	$\times 10^9$
9 电容	法拉(F)	法拉(F)	绝对法拉	厘米或静电法拉	$\times 10^9$
10 电阻		欧姆( $\Omega$ )	绝对欧姆	静电欧姆	$\times 10^9$
11 电导		安培(A)	绝对安培	静电安培	$\times 10^9$
12 电流	安培(A)	安培(A)	绝对安培	静电安培	$\times 10^9$

物理量	实用单位	24 绝对单位制			
		25 有理化的MKSA单位	98 CGS电磁单位	109 CGS静电单位	
单位	单位	单位	单位	单位	倍数
19 电阻	欧姆( $\Omega$ )	欧姆( $\Omega$ )	绝对欧姆	静电欧姆	$\times 10^9$
20 电阻率	欧姆·厘米	欧姆·厘米	绝对欧姆·厘米	静电欧姆·厘米	$\times 10^9$
21 电感	亨利(H)	亨利(H)	绝对亨利	静电亨利	$\times 10^9$
22 磁感应强度	韦伯/米 <sup>2</sup>	韦伯/米 <sup>2</sup>	绝对韦伯/米 <sup>2</sup>	静电韦伯/米 <sup>2</sup>	$\times 10^9$
23 磁化强度	安培/米	安培/米	绝对安培/米	静电安培/米	$\times 10^9$
24 磁场强度	安培/米	安培/米	绝对安培/米	静电安培/米	$\times 10^9$
25 磁导率	亨利/米	亨利/米	绝对亨利/米	静电亨利/米	$\times 10^9$
26 磁感应强度	高斯(G)	高斯(G)	绝对高斯	静电高斯	$\times 10^9$
27 磁通量	韦伯(Wb)	韦伯(Wb)	绝对韦伯	静电韦伯	$\times 10^9$
28 磁矩	安培·米	安培·米	绝对安培·米	静电安培·米	$\times 10^9$
29 磁阻	亨利/韦伯	亨利/韦伯	绝对亨利/韦伯	静电亨利/韦伯	$\times 10^9$
30 电导率	无单位	无单位	无单位	无单位	$\times 1$
31 磁化率	无单位	无单位	无单位	无单位	$\times 1$

注：1) 倍数是绝对单位与相应的实用单位的比值，绝对单位换算为实用单位时要乘相应的倍数。  
 2) CGS绝对单位与MKSA绝对单位的比值是CGS项的倍数除以MKSA项的倍数。  
 3) 两个CGS制单位之间的换算因素是根据电磁波在自由空间的传播速度为  $3 \times 10^{10}$  厘米/秒计算的。  
 4) 符号G代表高斯单位。

Table 3d 4. Unit Conversion Table of Electromagnetics

1. Physical quantity
2. Energy
3. Power
4. Quantity of electricity
5. Polarization strength
6. Electric potential
7. Electric field intensity
8. Dielectric constant

9. Electric capacity
10. Electric displacement
11. Electric flux
12. Electric current
13. Applied unit
14. Unit
15. Joule
16. Watts
17. Coulomb
18. Coulomb/centimeter<sup>2</sup>
19. Watts
20. Watts/centimeter
21. Farad
22. Amperes
23. Absolute unit system
24. Rationalized MKSA unit
25. Unit
26. Joule
27. Watts
28. Coulomb
29. Coulomb/meter<sup>2</sup>
30. Volts
31. Volts/meter
32. Farad/meter
33. Farad
34. Coulomb/meter<sup>2</sup>
35. Coulomb
36. Amperes
37. Multiple
38. CGS electromagnetic unit
39. Unit
40. Erg
41. Erg/second
42. Absolute coulomb
43. Absolute coulomb/centimeter<sup>2</sup>
44. Absolute watts
45. Absolute watts/centimeter
46. Absolute farad
47. Absolute amperes
48. Physical quantity
49. CGS static electric unit
50. Unit
51. Erg
52. Erg/second
53. Static electric coulomb
54. Static electric coulomb/centimeter<sup>2</sup>
55. Static electric volts
56. Static electric volts/centimeter
57. Centimeters or static electric farad
58. Static electric amperes
- 58a. Physical quantity

59. Resistance  
60. Resistivity  
61. Inductance  
62. Magnetic pole strength  
63. Magnetic strength  
64. Magnetic field strength  
65. Permeability  
66. Magnetic induction strength  
67. Magnetic flux  
68. Magnetic potential  
69. Magnetic reluctance  
70. Electric susceptibility  
71. Magnetic susceptibility  
72. Applied unit  
73. Unit  
74. Ohm  
75. Ohm·meters  
76. Henry  
77. Oersted  
78. Gauss/oersted  
79. Gauss  
80. Maxwell  
81. Gilbert  
82. Gilbert/maxwell  
83. Measureless  
84. Absolute unit system  
85. Rationalized MKSA unit  
86. Unit  
87. Ohm  
88. Ohm·meter  
89. Henry  
90. Weber  
91. Weber/meter<sup>2</sup>  
92. Ampere-turns/meter  
93. Henry/meter<sup>2</sup>  
94. Weber/meter<sup>2</sup> (or tesla)  
95. Weber  
96. Ampere-turns  
97. Ampere-turns/weber  
97a. Multiple  
98. CGS electromagnetic unit  
99. Unit  
100. Absolute ohm  
101. Absolute ohm·centimeter  
102. Absolute henry  
103. Oersted  
104. Gauss/oersted  
105. Gauss  
106. Maxwell  
107. Gilbert  
108. Gilbert/maxwell  
108a. Unit

- 109. CGS static electric unit
- 110. Unit
- 111. Static electric ohm
- 112. Static electric ohm·centimeter
- 113. Static electric henry
- 114. Multiple
- 115. Notes: 1) The multiple is the ratio of the

absolute unit and the applied unit. When converting the absolute unit into the applied unit it is necessary to multiply by the suitable multiple.

2) The ratio of the CGS absolute unit and KMSA absolute unit is the multiple of the CGS item multiple divided by the KMSA item multiple.

3) The conversion factor between the two CGS system units is calculated according to the speed of the electromagnetic wave in free space as  $3 \times 10^{10}$  centimeters/second.

4) The symbol G represents the gauss unit.

	6 烛/米 <sup>2</sup>	7 烛/厘米 <sup>2</sup>	8 烛/英尺 <sup>2</sup>	9 英尺-制	10 亚照提
1 烛/米 <sup>2</sup> (尼式)	1	0.0001	0.0929	0.2919	3.1416
2 烛/厘米 <sup>2</sup> (照提)	10000	1	929	2919	31416
3 烛/英尺 <sup>2</sup>	10.76	0.001076	1	3.1416	33.82
4 英尺-制	3.426	0.0003426	0.3183	1	10.764
5 亚照提	0.3183	0.00003183	0.02957	0.0929	1

Table 3e 5. The Conversion of Various Lighting Units

- 1. Candle/meter<sup>2</sup> (nit)
- 2. Candle/centimeter<sup>2</sup> (stilb)
- 3. Candle/feet<sup>2</sup>
- 4. Feet-lambert
- 5. Sub-stilb
- 6. Candle/meter<sup>2</sup>
- 7. Candle/centimeter<sup>2</sup>
- 8. Candle/feet<sup>2</sup>
- 9. Feet - lambert
- 10. Sub-stilb

## II. Terminology and Symbols

### Those Beginning With Foreign Letters

- a rays . A type of radiation which included 2 neutrons and 2 protons
- b rays . A type of radiation produced when changes occur in the atomic nucleus protons or neutrons
- e . Base of natural logarithm,  $e = 2.718282$
- M . Flight speed unit indicated speed of sound. 1M=1130 feet/second or 345 meters/second
- ppm . A unit of one millionth
- Q . Switch Pulse Laser. A type of pulse laser which is regulated by a Q switch. Its special feature is its pulse width which is very short and its power very high
- x ray . The bombardment by outside particles causes the atomic inner layer orbit of electrons to be hit and when the hole is filled by the outer layer orbit electrons energy is emitted and radiation is formed

### Two Strokes (in the first Chinese character)

- Artificial Habituation. Habituation attained through physical training in an artificial environment.
- Artificial Radiation Band. The radiation band created by artificial nuclear explosion in earth surroundings.
- Human Body Equivalent Röntgen. The biological effects produced by any ion radiation on the human body or mammal with an equivalent dose of 1 röntgen of x rays or gamma rays.
- Human Body Heat Production Quantity. The quantity of heat produced by human body metabolism.
- Human Body Heat Storage (Cold Debt, Heat Debt). The heat accumulated in the body when the human body metabolism production of heat is greater than the heat loss is called human body heat storage or cold debt. When the human body production of heat is less than the heat loss this is called negative human body heat storage or heat debt.

### Three Strokes

The Up and Down Step. The use of a stool or step that goes back and forth and up and down which allows the testee to perform a certain amount of movement. It is a testing method used to measure the physiological reactions and body load endurance under movement conditions.

Atmospheric Ions. The different sized molecular groups carrying positive or negative electric charges.

Kilocalorie. The quantity of heat needed to heat 1 kilogram of distilled water from 19.5°C to 20.5°C.

Aircraft. Flight apparatus such as various types of gliders, airplanes, rockets, guided missiles etc.

Aircraft Weightless Flight (Parabolic Flight). The method of an aircraft to use parabolic flight to realize short time (several seconds to several tens of seconds) during flight.

Habituation. The physical training the human body undergoes to acclimate (get accustomed to or adapt) to a type of environmental condition.

Dry Bulb Temperature, Air Temperature. The temperature measured by a common thermometer of the dryness maintained outside a mercury bulb.

### Four Strokes

Neutron Current. Commonly released during nuclear fission. Based on the difference of neutron energy this can be divided into slow neutrons (energy smaller than 1 electron volt), medium speed neutrons (energy is 1-500 kiloelectron volts) and fast neutrons (energy is 0.5-10 mega-electron volts). Neutrons do not carry an electric charge.

Molecular Sieve. A type of gas molecule absorbent. After absorption, the molecules can also go through reverse processing whereby they are released. If they are irreversible they cannot be recovered and are permanent (change or injure).

Partial Pressure. The pressure in each type of gas component in mixed gases.

Air Pressure Cabin, Pressurized Cabin, Low Pressure Cabin. The air pressure can be regulated in a test cabin. When the inside air pressure is higher than 1 atmospheric pressure this is called a pressurized cabin and when it is lower than 1 atmospheric pressure it is called a low pressure cabin.

Vapour Saturation. The level of water vapour composition in the air when it cannot be further increased.

Reaction Time. The time from when a signal appears to when there is a reaction.

Analyzer. Manages the sensory nervous system parts which is the management of all of the sensory parts from the sensors to the central nervous system.

Specific Heat. The quantity of heat required to raise the temperature of a single substance 1°C or lower it 1°C.

Solar Flares. The release of a large amount of energy in a relatively small area on the sun's surface.

Solar Proton Event. This is a solar flare event. It is so named because protons are the main component of the solar flare radiation.

Solar Cosmic Radiation. Radiation that comes from the sun.

### Five Strokes

Electron Volts (eV). The energy unit of radiation particles. 1 electron volt is equivalent to the energy attained after electrons pass through an electric field with a 1 volt potential difference. 1 electron volt =  $1.6018 \times 10^{-19}$  erg.

Full Habituation. When habituation has already reached a completed or near maximum level. After this, there is very little progress in habituation.

Strengthened Supply of Air or Pressurized Absorption, Absorption gas pressure is higher than surrounding pressure.

Nit A light unit equal to candle/meter<sup>2</sup>.

Endurance Limit of Major Complaints. The maximum limit humans can endure. When exceeding this limit by over 50% humans cannot endure the major complaints.



Biological Clock. The cycle rhythm of biological life activities.

Biological Equivalent Röntgen. The biological effects produced by any ion radiation on an organism (not counting photoelectric effects) with a 1 röntgen x ray or gamma ray dose.

Compensation Reaction. This is a type of compensatory physiological reaction by an organism to negative factors to strengthen the organism's endurance or decrease the negative effects.

Rutherford (Ru). Unit of radiation source strength. 1 Ru is equal to  $10^6$  nuclear decay per second (gamma particles, photons), that is  $1C = 3.7 \times 10^4$  Ru (C is curie).

White Noise. Includes various types of audible frequencies and equivalent noise pressure noise.

Positive Ions. Ions which carry a positive electric charge.

Ionization Radiation. Radiation which can cause substances to produce ionization.

#### Six Strokes

Mega 1 million

Photon Radiation. Photons are a type of electromagnetic wave and among them the ionization radiation properties have x rays and gamma rays.

Letter Delineation. Delineate designated letters in a lettered table.

Impulse. Also called nerve impulse - it is a type of nerve conducted physiological electric signal.

Light Beam Divergency. The level of light beam divergence towards the outside and it is measured by its angle of divergence ( $\phi$ ).

Secondary Radiation. The radiation produced after the original radiation is added to the substance.

After Effects. After the physical effects of certain types of environmental factors stop, certain physiological effects continue to exist for a certain period of time.

Effective Consciousness Time. The time from the beginning of anoxia to the loss of effective work ability. The loss of effective work ability is usually taken as a critical index.

After Effects Time. The time from after irritation stops to the elimination of after effects.

Mitosis. The chromosome fission filiform reaction process that occurs during cell fission is called mitosis.

Earth Radiation Zone. The radiation zone surrounding the earth. The inner radiation zone and outer radiation zone are delineated according to their distance from earth.

Blood Cell Specific Volume. The percent the blood cell volume occupies in the blood.

Red Vision. The appearance of red in the field of vision (seen when there is hyperemia or hemorrhaging in the eye and retina).

Grey Vision. Vision lost in peripheral field of vision.

Natural Habituation. Physical training in a natural environment and the attainment of habituation.

### Seven Strokes

Focus (of Infection or Excitation). Indicates the pathological change positions or physiological reaction (excitation) concentrated position.

Hearing Loss (Permanent Threshold Shift). After the effects of intense noise for a relatively long period of time there is a degree of permanent decline in hearing which cannot be recovered to normal. This type of decline in hearing is called hearing loss or permanent threshold shift.

Low Pressure Anoxia. Anoxia caused by extremely low oxygen partial pressure.

Initial Conditions. The conditions prior to the beginning of testing (or exposure).

Cold Point. The point of sensor distribution of cold sensed on the skin.

Anal Temperature. Rectal temperature which represents the deeper temperature of the human body.

Irritation, Irritation Reactions. A series of physiological pathological reactions caused by outside negative irritation.

Hearing Threshold Shifts, Hearing Fatigue and Temporary Threshold Shifts. With a certain period of time after intense noise there can be a certain decline in hearing and after a period of time hearing can gradually be recovered. This type of temporary hearing decline is called a hearing threshold shift or temporary threshold shift. The threshold shift whereby some people recover hearing in less than 2 days is called hearing fatigue.

#### Eight Strokes

Seasonal Shifts. There are great discrepancies in the weather at the same time at different earth latitudes. There seems to be a seasonal change from one place to another. This situation is called a seasonal shift.

Diopter (D). When used for the human eye it indicates the number of degrees of inflexion sustained by the eyes, 1 light transmission medium (eye medium) by outside light rays.

Curie (C or Cu). The number of changes per second of 1 gram of refined radium in balanced radon which is the number of its released gamma particles.  $1C = 3.7 \times 10^{10}$  particles/second.

British System Heat Unit (Btu). The amount of heat required to heat 1 pound of water  $1^{\circ}F$ .

Organelle. A general designation of the cell internal structure (submicrostructure) including mitochondria endoplasmic reticulum, Golgis apparatus, microfilament etc.

Brightness Ratio. This is the following ratio:

$$\frac{\text{target brightness-background brightness}}{\text{background brightness}}$$

Brightness Ratio Threshold. The smallest brightness ratio difference able to be discriminated.

Track. The path of radiation particles when they penetrate organism tissue.

Physical Equivalent Röntgen (rep). The radiation energy absorption of 83 erg caused per centimeter<sup>2</sup> of substance. As regards biological tissue, each gram of tissue absorbing 93 erg of radiation is 1 rep.

Empty Field of Vision. The empty non-structured field of vision in high altitude flight such as a clear cloudless sky and a black sky.

Space Direction. The judgement of posture conditions and the determining of position in space.

Attention Range. The greatest number of targets able to be mentioned after one glimpse.

Rad. At a given point, the energy absorbed in each gram if substance is 100 erg of radiation.

#### Nine Strokes

Angstrom (Å). Wavelength unit, 1 angstrom =  $10^{-10}$  meters.

Phase, Time Phase, Position Phase. Development stage or time.

Coherent Mutual interference of light

Total Air Pressure. The sum total of various gas component pressures in mixed gases.

Subnormal Less than normal yet not yet at a pathological level.

Relative Biological Effects. The ratio of various radiation doses and x ray or gamma ray doses needed to produce similar biological effects.

Relative Humidity.

$$\text{Relative humidity (\%)} = \frac{\text{Actual moisture partial pressure in the air}}{\text{Moisture partial pressure when there is moisture saturation}} \times 100$$

Signal/Noise Ratio. The ratio of signal and noise intensity.

Chromosome A type of structure able to have color in the cell nucleus which is related to heredity.

Negative Pressure Absorption. The absorption gas pressure lower than the surrounding pressure.

Pulse Repeating Frequency. The number of times the pulse repeats in each unit of time (seconds).

Vibration Resistance. It is calculated by the following formula:

$$\text{Vibration resistance} = \frac{\text{force}}{\text{displacement speed}}$$

Vibration Transmission Factor. The ratio of the actually measured vibration resistance ( $Z_1$ ) of a flexible system and the vibration resistance ( $Z_1$ ) of a non-flexible system of the same quality under similar conditions.

Vibration Transmission Coefficient. It is calculated by the following formula:

$$\text{Vibration transmission coefficient} = \frac{\text{Particle peak value vibration acceleration.}}{\text{Vibration stage peak value vibration acceleration}}$$

Coronary Circulation System. The blood vessel that supplies blood to the heart.

Lumen (lm). Light flux unit. An even light source point with a 1 candle light intensity which is the emitted light flux in a unit solid angle.

Lumen/Feet<sup>2</sup> (or Feet-Candle). Unit of illumination. 1 lumen/feet<sup>2</sup>=10.764 lambert.

Clock Monitoring. Monitor whether or not the hands of the clock are moving normally.

Stilb. Unit of brightness equal to candles/centimeter<sup>2</sup>.

Shield. An apparatus which covers and isolates certain radiation.

#### Ten Strokes

Candle (cd). Unit of light intensity. The total radiation light source of the freezing point of platinum is equal to 60 candle/centimeter<sup>2</sup>.

Rontgen (r). Radiated photon (x ray or gamma ray) energy causes the air ( $10^{\circ}\text{C}$ , one atmospheric pressure dry air) of each centimeter<sup>2</sup> to produce positive electric charges each with 1 static electric unit ion. In 1r=1 centimeter<sup>3</sup> air there is formed  $2.083 \times 10^9$  ion pairs.

Mountain Aborigines. People who grew up in the mountains.

Atomic Number (Z). The number of protons in any atomic nucleus.

Atomic Weight (A). The total number of protons and neutrons in any atomic nucleus.

Space Navigation. Navigation more than 100 kilometers from earth.

Spacesuit. Protective clothing worn by astronauts.

Space Sickness, Weightlessness Motion Sickness. A type of motion sickness produced by weightlessness.

Heat Convection. Cold fluids (including gases and liquids) shifts downwards while heated fluids shift upwards. There is lost or gained heat due to the flow of the fluids and this is called heat convection.

Candle Power. The specific upward light radiation intensity in a light source.

Formication. A sensation on the skin like an ant crawling on it.

Flash Blindness. Temporary visual impairment or a decreased vision caused by a strong flash of light.

Flash Critical Merging Frequency. The frequency when the flashing light frequency is accelerated until there appears to be a continual (solid) light ( a method for measuring visual ability).

Language Comprehension. The percent (%) of the correct reaction of the writer when words or sentences are read out.

Breaking the Sound Barrier. A type of kinetic reaction when flight speed breaks the speed of sound.

Aviation. Navigation below 100 kilometers distance from the earth.

Collimated Light (Pencil Straight Light ). Light which is pencil straight and not scattered.

Time Difference (Time Shift). There are differences in time at different points on earth called time differences. The time changes which occur when navigating from one place to another are called time shifts.

Oxygen Reverse Reaction. After serious anoxia, within a short period of time (several tens of seconds) of a scorching heat supply of oxygen the symptoms become more acute or there is twitching and loss of consciousness.

Supervisory Work. The supervision to see whether or not the instruments and signals are normal and whether they require processing signals.

Accumulated Effects. The accumulated effects of multiple exposure to negative environmental conditions to the human body.

Energy Absorption Rate. The percent of energy used in an organism and absorbed by the organism.

Oxygen Debt. The tissue oxygen deficiency created by violent muscle movement. There is a gradual compensation recovery period for this type of oxygen deficiency and therefore it is called oxygen debt.

Heat Conduction. Because there is physical contact with different temperature heat conduction there is a gain or loss of heat.

Heat Evaporation. Loss of heat due to moisture evaporation (such as perspiring).

Selection Reaction Time. When there is no stopping on one signal, the time from the occurrence of a signal to making a corresponding reaction.

Heat Radiation. The heat gain or loss due to radiation.

Tracking Control. A type of control work or control work efficiency test method. After certain control activities the indications on the indicator can overcome disturbances and be maintained in a fixed position (compensation tracking) or track a target with a tracker (tail tracking)

Octave. When the noise frequency doubles this is called an octave.

### Eleven Strokes

Lux (lx). Illumination unit of lumen/meter<sup>2</sup>.

Lambert (L) Unit of brightness. The strength of an evenly diffused light is lumen/centimeter<sup>2</sup>.

Milli (m). 1/1,000 which is 10<sup>-3</sup>.

Dimension, Dimensional, Degree. The coordinate system in physics such as three dimensional space. Six dimensional space movements which are shown in the six types of directional movements of up-down, left-right, forward-backward, bending-lifting, rolling and revolving.

Closed Ecosystem. The metabolic processes of life substances in a closed environment complement each other, realize equilibrium and do not require an outside supply. It also does not require an ecosystem to eliminate substances toward the outside.

Visual Angle. The size of the visual angle occupied by the visual target.

Milky Way Cosmic Radiation. The high energy band of electric particles from the various directions of the Milky Way system.

Gradient. Quantity differential.

Millilambert (mL), Microlambert ( $\mu$ L) A millilambert is 1/1,000 of a lambert; a microlambert is one-millionth of a lambert.

Deep Heat Effect. The heating effect of microwaves of less than 3,000 megacycles (especially less than 1,000 megacycles) often go beyond the surface tissue and affects the organism's deep tissues. Therefore, this type of phenomenon is called the deep tissue heat effect.

Denitrification. After a certain amount of time of breathing mixed gas with a deficiency of nitrogen, the dissolved nitrogen in the body is released and this acts as a measure of prevention against decompression sickness.

Visual Illusory Movement. When a fixed immobile target is viewed at for more than 30 seconds on an empty field of



vision background most people feel as if it is making irregular movements. This type of illusion is called visual illusory movement.

Visual Afterimage. After looking at a bright, relatively large object for some time there is still a remaining image before the eyes after the object is lost.

Visual Afterimage Continuation Time. The time for when the object is lost to when the afterimage is lost.

Visual Brightness Threshold. The minimum brightness visible to the human eye.

Visual Constancy (Visual Habits). Sometimes visual signals are not identical to the objective thing. For example, the visual image of an object shrinks according to distance but this does not signify that the objective has really shrunk. When people visually discriminate, the conformity of the central nervous system causes people's perception of the objective thing to be close to the reality of the thing and this is called visual constancy.

Dispersion. The physical phenomenon of a gas component diffusing from a higher partial pressure area to a lower partial pressure area.

Millimicro (mμ)  $10^{-9}$

#### Twelve STrokes

Maximum Oxygen Intake. The oxygen intake per minute when performing the strongest physical load.

Hub. When a needle is inserted in a given hole, it is maintained stable without running into the wall (one type of behavioral test is to calculate the number of times one runs into the wall within a given amount of time).

Intense Light Blindness (Eclipse Blindness). Retina harm caused by intense light.

Inert Gas. A non-sensitive gas in a chemical reaction (especially in the human body).

Temperature Points. The sensor distribution points of the heat felt on the skin.

Black Vision. The entire field of vision is lost and there is a feeling of a strip of black before the eyes.

Visual Sensitivity. The size of the visual angle occupied by the smallest target which can be discriminated by the human eye.

Wet-Bulb Temperature. Using a common thermometer, the measured temperature of the moisture maintained outside the mercury bulb.

Black-Bulb Temperature ( $T_g$ ). Using a thin walled copper bulb painted black on the outside with a diameter of 150 millimeters, the measured temperature of the thermometer mercury bulb placed in the center of the black bulb.

### Thirteen Strokes

Micro (M). One-millionth,  $10^{-6}$

Dark Light Field of Vision. The size of the field of vision when viewing an object under dark light conditions.

Troland. A retina lighting unit equal to one photon illumination on the retina.

Microwave Absorption Coefficient. This is calculated according to the following formula;

$$\begin{aligned} \text{Microwave absorption coefficient (centimeter}^{-1}\text{)} = \\ \frac{\text{The heating rate of each unit volume of} \\ \text{biotissue (millicalories/centimeter}^2\text{.seconds)}}{\text{Microwave intensity (millicalories/centimeter}^2\text{.seconds)}} \end{aligned}$$

Microwave Heat Effect and Non-Heat Effect. The heating effect of microwaves on organisms as well as the physiological and harmful effects created by heating. This is generally designated the microwave heat effect. Besides this, the other physiological effects of microwaves are jointly called microwave non-heat effects.

Scarcely Perceptible Pulse. A very weak pulse.

Critical Point, Critical Value. The turning point of physiological effects. When this value is surpassed certain physiological reactions or symptoms can occur.

Heat-Insulation Unit (clo). A male wears medium weight underwear, jacket, socks, shoes and pants when the wind velocity is 100 centimeters/second; or for a person sitting in a 21°C environment, the clothing heat insulation value required to wear to feel temperature comfort (relative humidity 50%, airflow 20/feet minute). 1clo clothing heat conduction resistance is 1 kilocalorie/meter<sup>2</sup>·hour·0.18°C.

#### Fifteen Strokes

Latent Heat Evaporation (Unconscious Perspiring). The direct evaporation of moisture from the skin or the minute water evaporation of perspiration (people cannot consciously sweat). There is a human body heat loss caused by this.

Treadle. A type of simulation equipment for measuring the physical load of walking.

Quantity Level. Each 10 fold is a quantity level.

Perception Time. The time from when a signal or stimulant appears to when it is discovered by a person.

#### Sixteen Strokes

Laser. A special type of light produced by a laser. When atoms, ions or molecules are in an excited state under the effect of photons there is formed excited radiation and a type of special light radiation is produced. This type of light is straight and possesses coherent special features so that its light pressure and power of destruction are much greater than ordinary light.

Growth Rate. The speed of the value increase.

Radiation Energy Shift, Rectilinear Energy Shift. The shift of radiation energy from basic particles to bio-tissue is called a radiation energy shift. Because particles penetrate tissues in a rectilinear manner and the radiation energy shifts it is called a rectilinear energy shift.

Irritation. An uncomfortable type of irritating feeling.

### Seventeen Strokes

Discrimination Threshold. The smallest excitation difference able to be discriminated.

Below the Threshold Limit. Lower than the threshold value strength.

Radiation. If there is a change in the structure of the atom there is the possibility of the absorption or output of energy. If particles or energy is emitted because of this it is called radiation.

Threshold Value, Threshold, Threshold Limit. The stimulation strength which can produce certain types of physiological phenomena.

### Eighteen Strokes

Instantaneous Memory. Extremely short memory.

### Nineteen Strokes

Ion Shift Rate. The distance (centimeters) ions move per second in each centimeter-volt<sup>2</sup> standard electrical field.

Eardrum Temperature. The temperature of the area of the tympanic membrane. This can represent the human body's cranial temperature and deep body temperature.

### Twenty-One Strokes and Above

Roaring Sounds, Sound Wave Explosions. The shock sound waves produced by supersonic aircraft.

Dew Point. The temperature when there is slow freezing in the atmosphere and dew begins to form. In this temperature, the moisture pressure is equal to the moisture saturation pressure in the atmosphere.

Picking Up a Pellet With a Tweezers. Using a tweezers to place a pellet from one place into a hole in another place (a type of manual efficiency test).

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